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Analysis of scientific argumentation in two physical chemistry classrooms using the POGIL approach

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ANALYSIS OF SCIENTIFIC ARGUMENTATION IN TWO PHYSICAL CHEMISTRY CLASSROOMS USING THE POGIL APPROACH

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This work is dedicated to chemistry students. May our instruction provide you with opportunities to learn science.

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ABSTRACT

Moon, Alena C. Ph.D. Purdue University, May 2016. Analysis of Scientific Argumentation in two Physical Chemistry Classrooms using the POGIL Approach. Major Professor: Marcy Towns.

The benefits of facilitating argumentation in science education have been well reported (Jimenez-Aleixandre & Erduran, 2007). Engaging in argumentation has shown to model authentic scientific inquiry as well as promote development of content knowledge. However, less emphasis has been placed on facilitating argumentation in upper level undergraduate courses, though it is important for evaluating undergraduate curricula to characterize upper level students' scientific reasoning. This work considers two implementations of the POGIL physical chemistry curriculum and evaluates the classroom argumentation. The researchers aimed to consider the content of the arguments and dialectical features characteristic of socially constructed arguments (Nielson, 2013). To do this, whole class sessions were videotaped and Toulmin's Argument Pattern (TAP) was used to identify the arguments generated during the class (Erduran, Simon, & Osborne, 2004). A learning progression on chemical thinking (Sevian & Talanquer, 2014) was used as a domain-specific measure of argument quality. Results show differences in argumentation between and across both classrooms that can be explained by analysis of instructor facilitation and the POGIL curriculum. The results from this

work will be used to make recommendations for instructor facilitation of argumentation and reform of the POGIL curriculum.

CHAPTER 1. INTRODUCTION

An emerging objective of science education is to enculturate students into a scientific community of practice that they may actively engage in science (Lave & Wenger, 1991). The science classroom must then include opportunities to consider scientific knowledge and how that knowledge is generated (Christodoulou & Osborne, 2014; Kuhn, 2010). One way of incorporating this is having students engage in scientific discursive practices, of which argumentation is key (Garcia-Mila & Andersen, 2007).

Argumentation is the practice of considering and weighing multiple arguments, which are discursive products including a claim justified with evidence (Bricker & Bell, 2008). Though there are variations in the structure and quality of arguments, which will be explored further in the next chapter, generating an argument requires the consideration of data or evidence to draw a conclusion. This practice has been crucial for advancing scientific knowledge (Bell, 2004; Bell & Linn, 2002). Unfortunately, traditional classrooms provide little opportunity for students to engage in this discursive practice (Driver, Newton, & Osborne, 2000; Berland & McNeill, 2010; Christodoulou & Osborne, 2014). The Process Oriented Guided Inquiry Learning (POGIL) is one approach that provides these opportunities to students. POGIL is an instructional method developed for undergraduate chemistry teaching. The POGIL project's aim is to provide instructional

materials that support collaborative learning, based on Vygotsky's theory of social constructivism. A POGIL classroom will often spend a large portion of the class in small groups. The rest of the class time may be spent in whole class discussion or smaller lectures. The curricular materials aim to guide students through a construction of a concept by considering experimental data, negotiating mathematical symbolism, and constructing models. The POGIL approach specifically aims at promoting epistemic practices, so it provides prompts expecting students to explain and articulate their understanding to each other. For this reason, a POGIL classroom is an appropriate context for considering students' discourse.

Most studies evaluating student discourse in an inquiry classroom have investigated primary and secondary levels. More work is needed at the tertiary level, especially in upper level chemistry courses (NRC, 2012). Specifically, undergraduate chemistry should build on the scientific practices taught at the secondary level (NRC K-12 Framework). However, there has been very little characterization of post-secondary students' participation in these scientific practices. To this end, this work will investigate POGIL physical chemistry courses. Thermodynamics is an upper level course that has traditionally been considered difficult for students, resulting in a plethora of alternative conceptions (Bain, Moon, Mack, & Towns, 2014). This provides motivation for considering how the use of an inquiry approach for thermodynamics hinders or supports students' discourse, which has shown to result in better conceptual learning and understanding of the nature of science (Bathgate, Crowell, Schunn, Cannady, & Dorph, 2015; Khishfe, 2014).

Successful argumentation is largely dependent on instructor facilitation (Becker, Stanford, Towns, & Cole, 2015; Christodoulou & Osborne, 2014) and the instructional context, including curricular materials and task goals (Berland & McNeill, 2010; Garcia-Mila, Gilabert, Erduran, & Felton, 2013). For this reason, these two dimensions were analyzed so as to possibly explain trends in argumentation observed in the two classrooms.

The study of physical chemistry students' discourse was guided by the following questions:

- How does the quality of argumentation vary between two POGIL physical chemistry classrooms?
    - How do differences in instructor facilitation influence the differences in argumentation that are observed?
- How does the quality of students' discourse in a POGIL physical chemistry classroom relate to the organization and prompts in a POGIL thermodynamics curriculum?

The answers to these questions will be used to inform the facilitation of the POGIL approach for student discourse and reform the POGIL curricular materials.

Overview of Chapters

Chapter two reviews the literature in scientific argumentation, evaluating the quality of arguments, the POGIL approach, difficulties in physical chemistry thermodynamics, and the theoretical foundations of this work. Chapter Three describes the methods that will be used to answer the guiding research questions. Chapter Four includes results from investigating and comparing the two classrooms, serving to answer

the first research question. Chapter Five reports results from analysis of the POGIL materials and the resulting argumentation. Chapter Six provides conclusions, implications for future research and practice, and recommendations for reform to the POGIL curriculum.

CHAPTER 2. LITERATURE REVIEW

Physical Chemistry

Physical chemistry has long been reputed as a difficult chemistry course. However, this claim tends to be assumed without much supporting evidence. A multitude of studies have identified alternative conceptions students hold regarding thermodynamics (Bain, Moon, Mack, & Towns, 2014; Greenbowe & Meltzer, 2003; Loverude, Kautz, & Heron, 2002; Meltzer, 2004; Nilsson & Niedderer, 2012; Thomas & Schwenz, 1998; Turányi & Tóth, 2013), quantum mechanics (Dangur, Avargil, Peskin, & Dori, 2014; Stefani & Tsaparlis, 2009), and kinetics (Bain & Towns, 2016). These studies are important for understanding potential misunderstandings students may leave a physical chemistry course with, but they do not help understand what makes physical chemistry particularly difficult. In this study, I argue that what makes physical chemistry difficult is its integration of scientific content (i.e., quantum mechanics, thermodynamics, kinetics) with scientific practices (i.e., developing and using models, using mathematics and computational thinking, analyzing and interpreting data). Sophistication in these practices is necessary to understand the content itself. For example, an ability to develop and use models is essential for understanding quantum mechanical models (Stefani & Tsaparlis, 2009), while an ability to analyze and interpret data is crucial to understanding concepts of energy transfer and thermodynamics.

The broader science education community has recognized this need for scientific practices, the means by which scientific knowledge is generated, to be taught explicitly in addition to scientific knowledge (NRC, 2012). Extending this perspective to the undergraduate level is necessary to build on students' secondary training according to new reforms (Cooper et al., 2015). Further, equipping students with an ability to engage in scientific practices has the potential to support an understanding of many concepts in chemistry, especially advanced chemistry (Stefani & Tsaparlis, 2009). Across science education, inquiry activities have been used to facilitate student engagement in more authentic scientific practices. There have been efforts to incorporate inquiry-based activities into the undergraduate chemistry classroom (Barthlow & Watson, 2014; Lewis & Lewis, 2008; Mitchell, Ippolito, & Lewis, 2012; Smithenry, 2010).

Process-Oriented Guided Inquiry Learning (POGIL)

One of the most pervasive efforts has been the use of Process-Oriented Guided Inquiry Learning (POGIL). This method uses small group discourse to promote the social construction of knowledge and a guided inquiry approach to support competency in both practice and concept knowledge. Within a POGIL classroom, the instructor assumes the role of a facilitator rather than a lecturer, moving towards a more student-centered approach. This approach aims to engage students in a learning cycle of exploration, concept construction, and application within each activity (Moog, Creegan, Hanson, Spencer, & Straumanis, 2006). The exploration section is initiated by a focus question. The students usually do not have the chemical knowledge necessary to answer the

question. The advantage of this is it prompts the students to explain what they do know, revealing to the instructor the students' prior knowledge on relevant concepts. The students then work through a series of critical thinking questions (CTQs) that build on previous units, information, and models specific to the activity. The final CTQs ask students to describe and explain the concepts that have been developed throughout the activity (Moog & Spencer, 2008).

Critical thinking questions for the thermodynamics curriculum range from mathematical problem solving to conceptual questions. In the activity on Gibbs and Helmholtz energy, students are guided through consideration of relationships between many relevant variables, derivation of the relationship between Helmholtz energy and work, and a reflection on how this quantity is used.

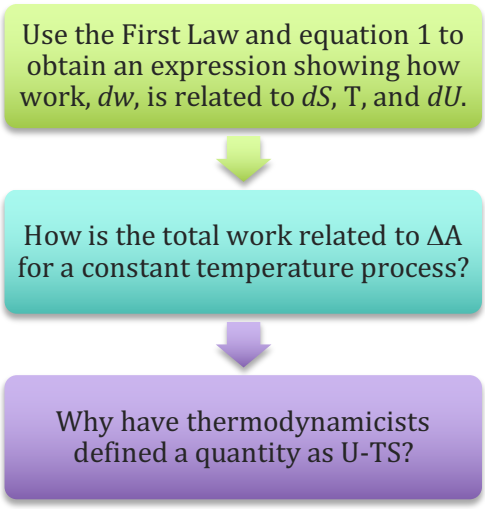


Figure 2.1. Examples of CTQs from each stage in the learning cycle for Helmholtz energy

Figure 2.1 demonstrates the types of problems students are expected to work through in developing models of thermodynamic variables. In the first question, students are expected to recall relationships that were derived in earlier units (prior knowledge). The second question indicates concept development of the concept of focus in the unit and the third question requires them to consider the value of quantifying Helmholtz energy, which will equip them to apply it. In the POGIL approach, the instructor organizes the class time as they think is best so POGIL classrooms differ in amount of time spent in small group, the presence of whole class discussions, and individual work expectations. The room for variation allows the instructor to cater the course to the needs of their classroom.

POGIL curricula have been designed for general chemistry, organic chemistry, biochemistry, analytical chemistry, and physical chemistry ("POGIL post-secondary", n.d.). Research has shown that POGIL has resulted in higher grades (Conway, 2014), better ACS exam scores (Hein, 2012), and improved students' attitudes (Straumanis & Simons, 2008). Some efforts to evaluate POGIL have investigated classroom discourse at the general chemistry and physical chemistry level (Becker et al., 2013, 2015; Kulatunga & Lewis, 2013; Kulatunga, Moog, & Lewis, 2013). As POGIL was developed based upon learning theories of social constructivism and situated learning, this method of evaluation is especially appropriate.

Classroom Discourse in Undergraduate Inquiry Chemistry

In a peer-led general chemistry course, Kulatunga and colleagues explored student and peer leaders' participation in discourse, using a lens of scientific

argumentation. To analyze students' participation in argumentation, they distinguished between individual and co-constructed arguments, distinguishing the highest level argument as one with a claim, evidence, justification, and rebuttal generated by more than one person. Twelve peer-led guided inquiry sessions, focusing on two small groups, were video-taped and transcribed. They found that students generated approximately 80% of all the arguments without intervention from the peer leaders and approximately 69% of all claims were supported by evidence and justification. Further, results indicate that in one group, 66% of the arguments were co-constructed, while in the other, 79% were co-constructed. Analyzing co-constructed arguments in more detail for participation patterns revealed that one group participated more equally in contributing to argumentation, while the other group had one member that dominated discourse (Kulatunga et al., 2013).

Kulatunga and Lewis (2013) also analyzed how peer leaders' verbal behaviors impacted discourse. They characterized eight verbal behaviors: direct teaching, short questions, encouraging, maintaining, probing and clarifying, acknowledging and validating, confronting discrepancies and clarifying options, and offering suggestions. The most prevalent verbal behaviors used by the two peer leaders were short questions and probing and clarifying questions. Considering only arguments generated with peer interventions, the short questions elicited a majority of the data components, while probing and clarifying questions elicited a majority of the warrant components. A conclusive finding was that combinations of verbal behaviors best supported argumentation (Kulatunga & Lewis, 2013).

At the physical chemistry level, Becker and colleagues (2013) identified a sociochemical norm of justifying claims with particulate-level explanations. The authors

investigated a POGIL thermodynamics classroom at a Midwestern comprehensive university. This classroom used both small group and whole class discourse. Results showed evidence of the sociochemical norm in arguments generated in both small group and whole class discourse. Use of particulate-level justifications followed a cyclical pattern. That is, they were present at the introduction of a concept, but became implicit as students became familiar with that concept (Becker et al., 2013).

In a separate analysis of the same classroom, Becker and colleagues (2015) investigated the role of the instructor in supporting translation across representational levels—macroscopic, sub-microscopic, and symbolic. To do this, they coded argument components for the representational level and coded instructor discursive moves with the Inquiry-Oriented Discursive Moves (IODM) framework. Their findings revealed that small group discussion consisted of largely symbolic reasoning while whole class discussion made use of more reasoning with multiple representational levels. They argued that this points to the value of small group work as an opportunity for students to negotiate mathematical meaning. Further, they found that the instructor had an important role in supporting translation across representational levels. Specifically, the pattern of instructor facilitation that consisted of questioning, repeating, and expanding (QRE) promoted more explicit consideration of multiple levels of representation in explanations.

Scientific Argumentation

All of the studies described above made use of scientific argumentation as a lens for considering students' discourse. Particularly, they used the Toulmin Argument Pattern (TAP), perhaps the most widely used model for characterizing arguments (Erduran,

Simon, & Osborne, 2004). Toulmin's (1958) model for arguments consists of a claim, supported by data, with a warrant serving to connect the data to the claim. These three components make up the core of an argument. There are other components, such as a backing, which provides the warrant authority, the rebuttal, which questions an argument, and a qualifier, which provides scope and limitations to an argument. Argumentation, then, is the practice of generating, considering, and comparing arguments (Garcia-Mila & Andersen, 2007). There has been growing interest in incorporating argumentation in the science classroom (Bricker & Bell, 2008) as explicitly teaching and facilitating argumentation invites students to participate in scientific discursive practices, which is highlighted as an objective in science education (Duschl, Schweingruber, & Shouse, 2007; Kelly, 2008). Some have posited that science must actually be taught as argument, which requires comparing scientific explanations to alternative explanations and justifying why scientific explanations are best for understanding phenomena (Bell, 1997, 2004; Kuhn, 2010; Ford & Wargo, 2012; Osborne et al., 2004; Sandoval, 2003). Adopting this perspective, engaging students in scientific argumentation not only allows them to participate in scientific practices, but supports their knowledge and understanding of scientific principles (Bathgate et al., 2015).

Strands of research in scientific argumentation have emerged in an effort to effectively incorporate it in the classroom. Some studies have explored instructor roles in facilitation of argumentation (Christodoulou & Osborne, 2014; McNeil & Pimentel, 2010; Simon, Erduran, & Osborne, 2006), in which instructors' contributions to classroom discourse were evaluated in the context of the whole class argumentation. A significant portion of work has emphasized how the curricular materials and classroom

settings hinder or support argumentation (Berland & McNeill, 2010; Alozie, Moje, & Krajcik, 2010; Garcia-Mila, Gilabert, Erduran, & Felton, 2013; Osborne, Erduran, & Simon, 2004). Some research has specifically explored the relationship between classroom norms and argumentation (Kuhn, Zillmer, Crowell, & Zavala, 2013; Cobb, Stephan, McClain, & Gravemeijer, 2001; Becker, Rasmussen, Sweeney, Wawro, Towns, & Cole, 2013). Fewer studies have explored the relationship between students' argumentation and their content knowledge (von Aufschnaiter, Erduran, Osborne, & Simon, 2008; Zohar & Nemet, 2002; Asterhan & Schwarz, 2007). Studies investigating the role of the instructor and curricular materials in facilitating argumentative discourse will be described in more detail, as they directly pertain to this work.

Instructor Facilitation of Argumentation

Christodoulou and Osborne (2014) studied the discursive actions of an experienced teacher aiming to teach argumentation in a 9th grade science classroom. The authors distinguished between teacher-performed and teacher-prompted argumentative discursive actions. Teacher-performed actions consisted of the instructor modeling argumentation practices (e.g. provides evidence, argument, counter-argument). Teacher-prompted actions consisted of the instructor eliciting argumentation practices (e.g. prompt for argument, prompt for evaluating, prompt for evidence). Christodoulou and Osborne (2014) provided examples of both of these types of discursive actions and the resulting student argumentation. They argued that to effectively teach argumentation, the instructor must simultaneously demonstrate argumentation practices during instruction and scaffold argumentation practices with students.

In an investigation of classroom discourse in three urban classrooms, McNeil and Pimentel (2010) specifically considered the role of the instructor in facilitating argumentation. The authors characterized teachers' questions as open, closed, rhetorical, or managerial and observed the resulting discourse from these questions. The classrooms differed in their patterns of argumentation. That is, one classroom had a high ratio of student to teacher (Ms. Baker) utterances, while the other two classrooms had the teachers (Mr. Dodson, Ms. Steven) speaking most. In the first classroom, one of Ms. Baker's discursive contributions resulted in multiple student utterances, which points to a more student-centered classroom. In addition to the higher quantity of student inputs in this classroom, the quality of arguments was higher with more evidence and reasoning used to support claims. When considering the different types of teacher questions, it was evident that Ms. Baker used more open questioning, which serves to explain the differences in argumentation between her classroom and the other teachers' classrooms. Open questions are content questions with multiple possible answers and for which the instructor is not seeking a specific response. These types of questions have the potential to support student discourse and the use of evidence and reasoning to justify claims (McNeill & Pimentel, 2010).

The same authors analyzed five teachers' discursive moves for facilitating discussion in the classroom and interviewed the teachers about their facilitation experiences (Pimentel & McNeill, 2013). In all of these teachers' classrooms, students' participation in class discourse was not very sophisticated, consisting of mostly single words or short phrases. Analysis of the teachers revealed that, even with a professional development workshop prior to the observed teaching, the classrooms were still largely

teacher-centered with fewer extended student responses. One concerning result from interviews was that the teachers expressed they did not feel equipped to facilitate whole-class discussions (Pimentel & McNeill, 2013). My study aims to address this insecurity expressed by teachers by identifying instructor moves that effectively facilitated discourse.

Simon, Erduran, and Osborne (2006) also investigated the impact of a professional development workshop for teachers on students' argumentation. They analyzed teachers' discourse and characterized a difference between prompting for argumentation and modeling argumentation, similarly to Christodoulou and Osborne (2014). As a result of the professional development workshop, approximately two-thirds of the instructors changed their practice. The authors argued that both modeling and prompting for argumentation serves to implicitly emphasize the value of argumentation in the classroom (Simon, Erduran, & Osborne, 2006).

All studies reported above consider the instructor to have an influential role in facilitating meaningful discourse. Certain types of questions, open-ended and probing, serve to elicit more sophisticated argument sequences from students and support student-student discourse. However, some teachers explicitly expressed discomfort with facilitating discourse or simply did not implement strategies suggested in professional development workshops. One way to address this is to identify more concrete ways instructors can contribute to student generation of sophisticated arguments.

Curricular Materials Influence

In addition to instructor facilitation, the curricular materials and instructional context impact argumentation. Building on their work in facilitating argumentation in the science classroom, Berland and McNeill developed a learning progression for scientific argumentation (2010). This learning progression described three different dimensions of argumentation: instructional context, argumentative product, and argumentative process. They describe a progression from simple to complex along each dimension. An ideal instructional context for facilitating argumentation includes open-ended questions with large data sets and limited scaffolding (Berland & McNeil, 2010). Though this is difficult to achieve in a classroom with time and material constraints, efforts to incorporate elements of this recommendation are crucial to support effective discourse. The POGIL approach is a reformed curriculum that meets some of these requirements for facilitating discourse. However, the extent to which certain types of problems/prompts contribute to argumentation has not been well studied.

Garcia-Mila and colleagues (2013) found that the task goal impacted the quality of resulting argumentation. Specifically, they separated dialogue groups into two conditions, persuasion and consensus, and evaluated the argumentation. The persuasion group was tasked with convincing the other person of their position using justified claims. The consensus group, on the other hand, was tasked with reaching a consensus solution using evidence based claims. Results showed that the consensus group generated more complex argument structures with more two-sided reasoning. The consensus group also generated more rebuttals than the persuasion group. The authors argue that this is because students in the consensus group were more likely to acknowledge the limitations

of their claims, while the persuasion group were less likely to acknowledge limitations in their argument in order to make it more convincing (Garcia-Mila et al., 2013). A separate analysis revealed that the persuasion group also repeated the same argument more frequently than the consensus group (Gilabert, Garcia-Mila, & Felton, 2012).

Investigation of the effect of curricular materials or instructional context on argumentation has been sparse. Berland and McNeil (2013) showed that argumentation prompts with larger data sets, open-ended questions, and little scaffolding support more sophisticated argumentation. Garcia-Mila and colleagues showed that the goal of the task prompting argumentation has an impact on the resulting argumentation. Specifically, when the students are prompted to reach consensus, they generate more rebuttals and complex argument structures(Garcia-Mila et al., 2013; Gilabert et al., 2012). However, more work is needed to understand the relationship between the curricular materials and the structure and nature of resulting argumentation.

Evaluating Scientific Argumentation and Reasoning

In the studies reported above that investigated the influence of instructional context and instructor on argumentation, argument sophistication was assigned based on structure. This is widely how arguments have been evaluated, especially those using the Toulmin Argument Pattern (TAP) (Erduran, 2007). Erduran's (2004) approach to characterizing levels of quality of argumentation is shown in Table 2.1.

Table 2.1. Analytical framework for evaluating the quality of scientific argumentation using TAP (reproduced from Erduran et al., 2004).

Analytical Framework Used for Assessing the Quality of Argumentation	
Level 1	Level 1 argumentation consists of arguments that are a simple claim versus a counter-claim or a claim versus a claim.
Level 2	Level 2 argumentation has arguments consisting of a claim versus a claim with either data, warrants, or backings but do not contain any rebuttals.
Level 3	Level 3 argumentation has arguments with a series of claims or counter-claims with either data, warrants, or backings with the occasional weak rebuttal.
Level 4	Level 4 argumentation shows arguments with a claim with a clearly identifiable rebuttal. Such an argument may have several claims and counter-claims.
Level 5	Level 5 argumentation displays an extended argument with more than one rebuttal.

Many studies evaluating argumentation have used or built upon this framework proposed by Erduran et al. (2004). One weakness of this framework is that it only considers structure of arguments/argument sequences and neglects to consider disciplinary epistemic criteria or scientific content (Clark & Sampson, 2008). Researchers have attempted to address this weakness with the development of new frameworks for evaluating argumentation (Kelly & Takao, 2002; Sandoval & Millwood, 2005; Sandoval, 2003; Takao & Kelly, 2003; Zohar & Nemet, 2002). Ultimately, the framework for assessing arguments will vary according to the researcher's desired qualities in an argument. In this work, a list of criteria for establishing argument quality was developed to consider the sophistication of arguments and the impact on discourse as a whole. This will be described in greater detail in Chapter 3. Students' use of causal reasoning was evaluated to characterize the complexity of arguments.

In considering student reasoning, the next generation science standards (NGSS) framework for K-12 science education in the United States identifies crosscutting

concepts that span scientific inquiry (NRC, 2012). Of these concepts, the most relevant for this study was building arguments using cause and effect, or mechanisms. Cause and effect descriptions serve to answer the "why" and "how" scientific questions. The framework highlights how cause and effect mechanisms range in complexity depending on the system being investigated. This capacity to generate mechanisms that use cause and effect is also important to explicitly teach at the undergraduate level as research suggests chemistry experts possess this skill (Sevian & Talanquer, 2014).

This study considers the overall scientific reasoning and use of causal models in classroom arguments. Research shows that more expert-like causal models are dynamic, integrated, and complex (Perkins & Grotzer, 2005; Brown et al., 2010). However, the causal models that students or novices generate and draw upon tend to be linear and oversimplified (Grotzer, 1993; Perkins & Grotzer, 2005). Further, novices can focus on single salient features of a problem or phenomenon and assign them total causal agency (Smith et al., 1985; Perkins & Grotzer, 2005; Sevian & Talanquer, 2014). However, explicitly teaching different causal models results in students using more complex models in their explanations (Perkins & Grotzer, 2005).

This body of literature largely focuses on primary and secondary students. Less work has been done with upper level science, technology, engineering, and mathematics (STEM) students to evaluate their scientific reasoning and use of scientific mechanism (Taber & Watts, 2000). Though expectations for chemistry undergraduate students' skills vary across institutions, this lack of research in the post-secondary chemistry classroom is indeed a gap considering that students nearing the end of their degree should ideally possess competencies essential to being a professional chemist (ACS CPT, 2015). In one

study, Sevian and Talanquer (2014) interviewed chemists ranging from undergraduate students to chemistry faculty members (representing a novice to expert range) using the GoKart question (Szteinburg et al., 2014). One goal of their work was to elicit the types of reasoning employed by the participants and describe a learning progression for chemical thinking that characterizes qualitatively different levels of reasoning about chemical processes. This learning progression is valuable for characterizing chemistry students' reasoning, specifically students' use of causal reasoning. As this progression is grounded in a theoretical commitment to a focus on disciplinary [chemistry] core practices, it serves as a domain-specific measure of argument quality. This progression will be described in greater detail in the methods with a description of how it was used to analyze data in this study.

Theoretical Frameworks

Sociocultural Perspective

Learning, both individual and collective, occurs through social interaction. Vygotsky argued, "The social dimension of consciousness is primary in time and in fact. The individual dimension of consciousness is derivative and secondary" (Vygotsky, 1978, p. 30, cited in Wertsch & Bivens, 1992). Learners construct knowledge together as they engage in joint activities in which they internally process the social interactions. Learning is the process of internalizing the effects of social interactions, which instigate internal mental development (John-Steiner & Mahn, 1996; Palincsar, 1998).

To explain a learner's development, Vygostky theorized the zone of proximal development (ZPD). ZPD consists of two different levels of development: the actual and the potential. The actual is the level of development the student possesses independently of others while the potential refers to the development possible with assistance from others. In order for learning to occur, it must be situated in the potential developmental level, thus being ahead of a student's actual developmental level (Vygotsky, 1981, p.137). In order to maximize the student's ZPD, the classroom must make use of joint, social activities.

A fundamental principle of the sociocultural perspective is that all learning is mediated by semiotics (Wertsch, 1991). Semiotics encompasses language, symbols, conventions, graphs, etc. (Vygotsky, 1981, p.137). These semiotic tools are used to co-construct knowledge as well as internalize knowledge. Motivated by this, the sociocultural perspective places value in evaluating discourse as the quality of discourse relates directly to the process of internalization (Mercer, 2004).

To evaluate learning through the lens of language, a genetic or developmental analysis method is most appropriate. As learning is grounded in a social, cultural, and linguistic context, it is necessary to identify the development of these contexts to understand how they relate to the internalization process. This method of analysis, considering the source of development over time, is necessary to understand learning and its relationship with language from a sociocultural perspective (John-Steiner & Mahn, 1996).

The primary tenet of the sociocultural perspective is that knowledge is co-constructed by individuals in a social and cultural context through the median of

language (Geelan, 1997). The social construction and individual construction of knowledge occur simultaneously and are interdependent (John-Steiner & Mahn, 1996). Vygotsky theorized that *intermental* (social) activity promotes *intramental* (individual) learning (Mercer, Dawes, Wegerif, & Sams, 2004). This occurs through a process of internalization by the individual. This learning process is housed in discourse. Therefore, the success or failure of an educational intervention may be attributed to the quality of the discourse rather than simply the students' or teacher's capabilities (Mercer, 2004).

The sociocultural perspective theoretically supports this work in its justification of the use of POGIL for facilitating small group and whole class discourse as a means of supporting individual understanding. It further supports the method of analysis used in this study. As learning is mediated by language, analyzing the classroom discourse is the most appropriate method for identifying instances of learning or discursive moves that hindered learning.

Situated Learning

In conjunction with the sociocultural perspective, the theory of situated learning argues that learning is the process of being enculturated into a community of practice (Lave & Wenger, 1991). The underlying premise is that learning is situated within social and cultural contexts, extending beyond the individual (Wertsch, 1984). Within this framework, then, there are conceptual and physical tools specific to the social and cultural contexts in which learning is taking place (Schoultz, Saljo, & Wyndham, 2001).

In the context of this work, thermodynamics is the content that a specific community of people studies, researches, and understands (Wenger, 1998, 2000).

According to situated learning, learning is the process of participating in that community. A student or novice begins on the peripheral of a community, learns conceptual and physical tools used by the community, and begins using those tools to participate in the community of practice (Sadler, 2009). Ongoing opportunities to authentically engage in practices of this community facilitate the development of these tools.

Situated learning provides two key assumptions that inform this work. Firstly, students must be provided discursive opportunities if they are to be able to engage in a scientific community of practice. Secondly, the goal of a thermodynamics course is to provide students the conceptual tools that members of the community of practice use and then allow students to use those tools.

CHAPTER 3. METHODS

Research Questions

The study of physical chemistry students' discourse was guided by the following research questions:

- How does the quality of argumentation vary between two POGIL physical chemistry classrooms?
    - How do differences in instructor facilitation influence the differences in argumentation that are observed?
- How does the quality of students' discourse in a POGIL physical chemistry classroom relate to the organization and prompts in a POGIL thermodynamics curriculum?

The theory and methods that will be used to answer these research questions will be presented in this chapter.

Theoretical Frameworks

The sociocultural perspective and situated learning provide the theoretical foundations for this study. Within the sociocultural perspective, learning is defined as an interdependent development of both the intermental (social) and intramental (psychological) (Vygotsky, 1978; John-Steiner & Mahn, 1996; and Mercer, 2004).

Learning is then mediated by language through discourse. An important implication of this framework is the importance of understanding the relationship between the intermental, intramental, and discourse. Because knowledge is constructed socially through discourse, the success or failure of learning can be associated with the quality of the discourse that took place (Mercer, 2004). This prompted the investigation of the relationship between learning and discourse quality in this study.

Situated learning provides the theoretical assumption that students are learning thermodynamics by engaging in the discursive practices of the thermodynamics community. In this way, it is necessary to explicitly teach both conceptual knowledge and epistemic practices of the thermodynamics community, which provides students with the necessary tools to engage in the community. In order to promote this participation, students' use of these tools must be evaluated. This study aims to evaluate how students use conceptual tools to engage in discursive practices.

Analytic Framework

This work utilizes Toulmin's (1958) framework for argumentation as it has been conceptualized and applied by Erduran et al. (2004). Toulmin's Argument Pattern (TAP) is used to identify and organize arguments (Erduran, 2007).

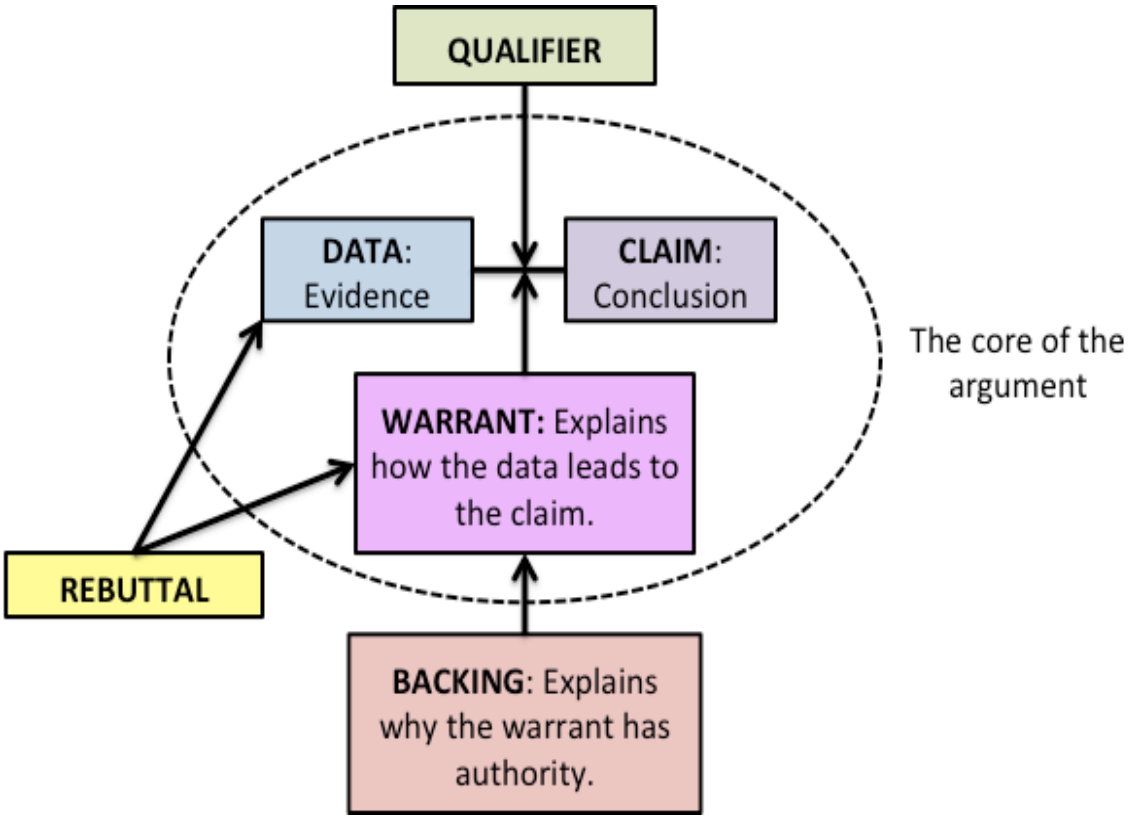


Figure 3.1. Toulmin's argument pattern (Toulmin, 1958)

The core of the argument includes a conclusion or, most frequently in this work, a suggested answer to a problem, some data or evidence, and an explanation connecting the former two. In certain instances, backings are required to justify or support a warrant. Qualifiers provide the limitations or scope to the core of the argument. In the context of physical chemistry, qualifiers often appear as a description of limitations for a formula or concept. Rebuttals identify a shortcoming in an argument by undermining either the use of a component in the core argument or the content of a component in the core argument. Often, a rebuttal is followed with a counter argument that serves to further explain the rebuttal.

This model for arguments is used to identify and organize the arguments. Claims are identified as a conclusion or proposed solution to a problem. The presence of evidence or data to support the claim qualifies it as an argument. Perhaps the most challenging step in using TAP is distinguishing between claims, data, warrants, and backings (Erduran, 2007). Indicator words such as "so" or "because" are useful for identifying what is being concluded (claim) or why the conclusion is drawn (warrant). For arguments concerning phenomena or empirical data, warrants frequently serve an explanatory purpose. For arguments concerning mathematical derivations or problems, warrants tend to be more algorithmic describing the steps taken to move from the data to the claim (Rasmussen & Stephan, 2008). Both types of arguments are present in physical chemistry discourse.

Methods

This study is part of a larger project being done in collaboration with other chemistry education researchers. The research team consists of two chemistry education faculty members (one of whom was the instructor in classroom B), one other chemistry education graduate student, and myself. The research team collaborated to generate the argument logs and then graduate researchers analyzed argument logs separately.

Participants and Setting

Data were collected at two universities utilizing the POGIL approach in their physical chemistry classroom. The first set of data was collected at a central Midwestern university in Fall of 2010. The professor of the course was experienced in teaching with

the POGIL curriculum as she had been using the POGIL approach in her physical chemistry course for eight years. All students were juniors and seniors pursuing a Bachelor's of Science in chemistry and chemical engineering (n=18, 13 males, 5 females). The class met twice a week for one hour and fifteen minutes each time. In this implementation of POGIL, small groups wrote their answers and explanations on a small white board that was used to present to the whole class. Between a third to a half of class time was spent in small groups, while a half to two thirds of the time spent in whole class discussion.

The second data set was collected at a small Midwestern college in 2013. While the previous class focused entirely on thermodynamics, the physical chemistry courses at this college covered multiple physical chemistry topics (kinetics, thermodynamics, quantum mechanics, and spectroscopy) in physical chemistry I and physical chemistry II. The difference between physical chemistry I and physical chemistry II was the depth with which topics were treated. Only lessons devoted to thermodynamics will be evaluated in this work.

The instructor at the college had used the POGIL approach for seven years by 2013. The students in this physical chemistry course sequence ranged from sophomores to seniors and represented a broader range of majors including chemistry, biology, biochemistry, physics, and math. At this college, the laboratory course was combined with the lecture component in such a way that all class time was divided equally into lecture, small group work, and laboratory. These implementations only included small group work rather than alternating between small group and whole class discussion, as was the case for Classroom B.

Table 3.2. Participant demographics for two classrooms observed in this study

<table>
<tr><td></td><td colspan="2">Classroom A</td><td colspan="2">Classroom B</td></tr>
<tr><td></td><td colspan="2">Instructor A</td><td colspan="2">Instructor B</td></tr>
<tr><td>Instructor Experience</td><td colspan="2">7 years of implementing POGIL</td><td colspan="2">10 years of implementing POGIL</td></tr>
<tr><td rowspan="3">Setting</td><td colspan="2">Private College, ~1000 students</td><td colspan="2">Public University, ~14,000 students</td></tr>
<tr><td colspan="2">Physical Chemistry I & II</td><td colspan="2">Thermodynamics</td></tr>
<tr><td colspan="2">Spencer, Moog, and Farrell POGIL materials</td><td colspan="2">Spencer, Moog, and Farrell POGIL materials</td></tr>
<tr><td rowspan="2">Number of Participants</td><td rowspan="2">10 students</td><td>3 Females</td><td rowspan="2">18 students</td><td>5 Females</td></tr>
<tr><td>7 Males</td><td>13 Males</td></tr>
<tr><td rowspan="2">Participant Demographics</td><td colspan="2">Second through Fourth years</td><td colspan="2">Third and Fourth year students</td></tr>
<tr><td colspan="2">2 semester of Calculus (except 1)</td><td colspan="2">At least 1 semester of Calculus</td></tr>
<tr><td>Class Time</td><td colspan="2">1/2 to 2/3 time small group work and 1/3 to 1/2 lecture</td><td colspan="2">1/3 to 1/2 class time small group work, rest whole class discussion</td></tr>
</table>

Data Collection

Data collection modeled a methodology originating in mathematics education for documenting collective activity (Cobb & Whitenack, 1996; Rasmussen & Stephan, 2008; Cole, Becker, Towns, Sweeney, Wawro, & Rasmussen, 2012). This method is especially apppropriate for considering classroom discourse over a period of time. To this end, whole class periods were videotaped. In the case of the 2010 fall semester implementation, video data of two months of the course were collected. In 2013, courses were videotaped for their entire duration, though only thermodynamics activities will be evaluated for this work. To capture small group interactions, one small group was videotaped during each class period. All videos are transcribed verbatim. Students were assigned pseudonyms to protect their identity.

Data Analysis

Data analysis occurred in multiple stages. An overview of the different stages is provided in Figure 3.2.

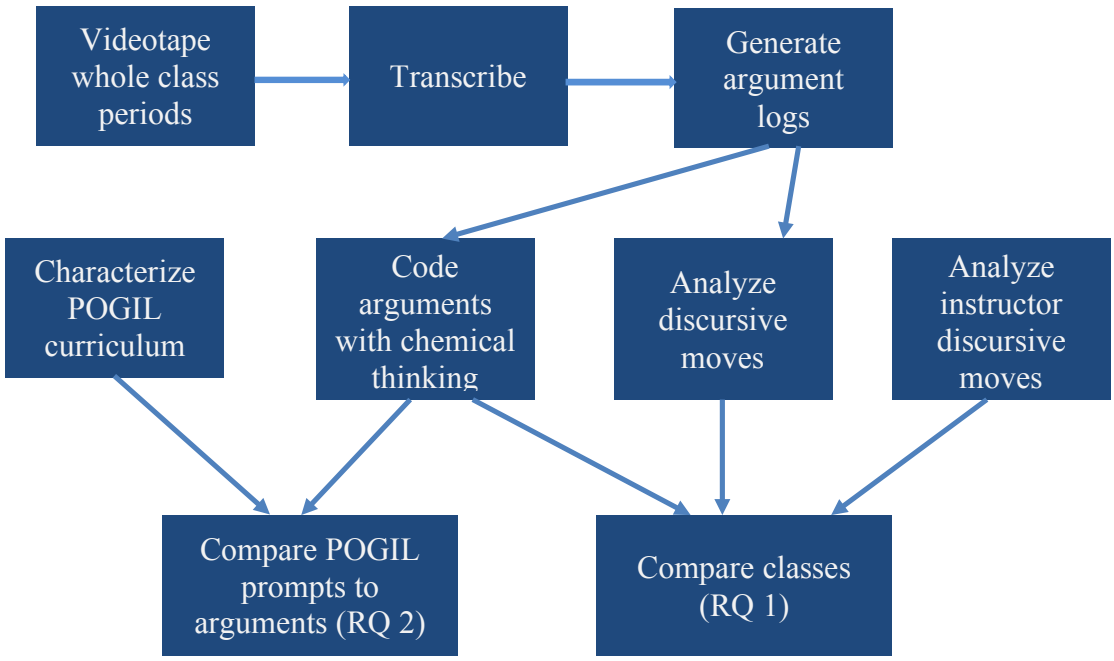


Figure 3.2. Overview of data analysis

Argument Log Generation

To generate argument logs, transcripts are coded using TAP. This involves identifying claims, which usually correspond to answers to critical thinking questions in the POGIL curriculum. If a claim is supported with data or evidence, they are considered an argument. The whole episode containing the claim and data is framed according to TAP. The other graduate student on this project and I individually coded transcripts for arguments and then met with the entire research team to confirm our interpretation and

generate a consensus argumentation log. A majority of the arguments included paraphrased statements aimed at capturing the meaning the students and instructor aimed to convey. Paraphrases were also used when multiple statements conveyed only one component of an argument. If the meaning could not be clearly derived from the student's words or the argument component corresponded to one statement, their exact statements were used and italicized in the argument logs. This method provides a means of condensing the large amount of text resulting from classroom discourse to smaller, clearer episodes that can then be analyzed.

Analysis of Discursive Moves

TAP is an effective method for identifying and organizing arguments. One of the limitations with using this method is that it frequently neglects the content of an argument. Rather, quality of argumentation is awarded according to structural complexity; that is, the presence of warrants, rebuttals, and counterarguments indicates better argumentation (Erduran et al., 2004). In this study, a list of criteria for evaluating arguments was developed and used to analyze arguments. The list of criteria is shown in Table 3.3.

Table 3.3. List of criteria used to evaluate discourse in both classrooms.

Argument Feature	Source
Claim agrees with scientifically accepted knowledge	Sampson & Clark, 2008
Claim draws on sufficient evidence/data	Toulmin, Reike, & Janik, 1984
Data is reliable	Sandoval, 2003
Data is relevant to problem and/or claim	Toulmin, Reike, & Janik, 1984
Data is complex, complete, and thorough	Preliminary analysis
Warrant agrees with scientifically accepted knowledge	Sampson & Clark, 2008
Warrant connects data to claim	Toulmin, 1958
Warrant is relevant to the problem/claim	Toulmin, Reike, & Janik, 1984
Warrant represents complexity of problem/explanation	Preliminary analysis

This list was generated using an iterative design process and drawing from three domains: literature on argument evaluation, the argument logs, and Toulmin, Reike, and Janik (1984). As I began considering the content of the arguments, I identified types of weak arguments. These were considered to develop items on the criteria list. For example, consider the following argument:

> **Claim**: Work is done
> **Data**: Because the piston moves
> **Warrant**: The movement of the piston is the change in delta h (height)

Though the claim and data are sound and scientifically correct, the warrant provides no connection between the two. This argument fails to effectively justify the process of work because it does not provide an explanation of how the movement of a piston (data) indicates the occurrence of work (claim). This example illustrates that an argument is

only effective if it includes a warrant that provides this connection, leading to the criterion "warrant connects data to claim."

Some of the qualities considered in an argument that emerged from the literature were validity and reliability of data cited (Sandoval, 2003) and whether or not the content of the argument agreed with scientifically accepted explanations (Sampson & Clark, 2008). In addition to these values, there are qualities that ensure that an argument is reasonable and potent (Toulmin, Rieke, & Janik, 1984). These include sufficiency of data, relevancy of data, explicit reference to assumptions, and absence of ambiguities.

Initially these criteria were generated in the form of a rubric. Using a 3-point scale, the rubric was tested against the data in order to determine whether or not the items on the rubric were appropriate for describing the arguments. To ensure content validity, the research team considered each item on the rubric. All argument logs were coded using the rubric items as nodes in the qualitative analysis software, Nvivo 10. For each argument, the claim, data, and warrant were coded by being assigned a score. However, analysis using the items as a rubric with the 3-point scale revealed that the rubric failed to discriminate between the two classrooms in a meaningful way. Further, it did not capture the discursive differences between the two classrooms.

Analysis using the rubric revealed that arguments tended to satisfy the criteria presented in Table 3.3 or not. This prompted a switch from a rubric to list of criteria with a binary consideration of argument quality. That is, an argument either met the criteria or it did not. Further analysis also revealed that differences between the two classrooms were not due to weaknesses within arguments, but rather how those argument components impacted discourse as a whole. This prompted a broader investigation of

how argument components served to support and hinder argumentation. To understand this phenomenon, argument components were interpreted as a positive or negative discursive move. A positive discursive move was one that served to promote discourse, while a negative discursive move served to hinder discourse. This framework was also used to consider instructor facilitation. That is, when comparing the instructor facilitation, how an instructor modeled or elicited positive discursive moves was considered.

Use of Chemical Thinking

The modes of reasoning from a learning progression on chemical thinking was used as a domain-specific measure of argument quality (Sevian & Talanquer, 2014). Learning progressions characterize possible levels of understanding that students may progress through as they work towards some final understanding of a concept. A learning progression on chemical thinking is useful for characterizing the level of reasoning exhibited in an argument. Chemical thinking is defined as "The development and application of chemical knowledge and practices with the main intent of analyzing, synthesizing, and transforming matter for practical purposes (Sevian & Talanquer, 2014)." An authentic practice like argumentation in an advanced chemistry course is especially apt for revealing students' chemical thinking. This learning progression defines six crosscutting disciplinary concepts in chemistry, which are presented in Table 3.4.

Table 3.4. Crosscutting disciplinary concepts, from Sevian and Talanquer (2014)

Crosscutting disciplinary concept	Core Question
Chemical identity	How do we identify chemical substances?
Structure-property relationships	How do we predict the properties of materials?
Chemical causality	Why do chemical processes occur?
Chemical mechanism	How do chemical processes occur?
Chemical control	How can we control chemical processes?
Benefits-costs-risks	How do we evaluate the imacts of chemically transforming matter?

The learning progression then defines levels of reasoning across all of these crosscutting disciplinary concepts. Essentially, lower level chemical thinking involves a surface interpretation of a problem, but higher level chemical thinking involves considering and weighing multiple variables that contribute to an outcome or explain a problem. These levels are presented in Table 3.5.

Table 3.5. Learning progression in chemical thinking, modified from Sevian and Talanquer (2014)

Descriptive	• Salient properties are recognized • Explicit properties are verbalized • Phenomenon is instantiation of reality • Reasoning based on experiences from daily life
Relational	• Explicit and implicit properties are highlighted • Spatial and temporal relations are noticed • Phenomenon is effect of single mechanism (no mechanism)
Linear	• Mechanisms proposed that involve linear cause-effect relationships
Multicomponent	• Mechanism weighs effects of several variables
(a) Isolated	• Mechanism weighs effects of several variables separately
(b) Integrated	• Mechanism depends on the dynamic interplay between multiple variables

All arguments were assigned a code that included the appropriate crosscutting disciplinary concept and level of chemical thinking. For example, a code might look like "Chemical mechanism: Relational." Analysis revealed that the crosscutting disciplinary concepts did not serve to provide meaningful insight about the arguments because the physical chemistry course as a whole tended to target only chemical mechanism or chemical causality. For this reason, only the modes of reasoning were used to code. This served to characterize the complexity of arguments generated in both classrooms.

Analysis of Curricular Materials

The POGIL physical chemistry curriculum was analyzed using the Task Analysis Guide for Science (TAGS) (Tekkumru-Kisa, Stein, & Schunn, 2015). This framework evaluates tasks along two dimensions: cognitive demand and content-practices integration. It was specifically designed to consider how classroom tasks target scientific content and the scientific practices characterized by the NGSS in an effort to promote better assessments of the practices. This was an appropriate framework for evaluating the POGIL curriculum as one of its objectives as an inquiry approach is to engage students in scientific practices in addition to learning content knowledge.

Only the POGIL Activities covered in both classrooms were considered in this analysis. Each question was assigned a TAGS label. If a question had sub-questions, all were considered one unit to be assigned a TAGS label. The TAGS framework along with examples of how it was used will be presented in detail in Chapter 5 prior to the results.

Reliability and Validity

Evidence for the validity and reliability of the results from this work sources from the methods chosen to investigate physical chemistry students' reasoning. Within the post-positivist research paradigm, a case will be made for the trustworthiness of the results presented in Chapters 4 and 5 (Golafshani, 2003). The data collection method for this research was chosen for its appropriateness for documenting collective activity (Cobb & Whitenack, 1996). Cobb and Whitenack (1996) argue for the trustworthiness of this data collection method by citing two considerations that are relevant for this study. The first consideration is that data is analyzed iteratively so that initial conjectures are continually tested against the data throughout analysis. The second is the level of critique this interpretation has received from peers. In this case, this measure of trustworthiness is especially appropriate, as the peers that critiqued this analysis were part of the research team and possessed extensive familiarity with the participants, settings, data, theory, and research objectives.

Steps were taken in each stage of analysis to ensure trustworthiness. The argument logs were generated independently by two researchers and confirmed by consensus with the whole research team. The criteria used to determine argument and discourse quality were also evaluated by the whole research team. To determine the reliability of coding with the modes of reasoning, interpretations of the modes of reasoning with other chemistry education researchers. Finally, to test the appropriateness of TAGS assignments to the POGIL prompts, prompts that were confusing or unclear for me were tested with an entire group of chemistry education researchers. These steps

incorporate aspects of investigator triangulation supporting the trustworthiness of this study and its results (Golafshani, 2003).

Limitations

The method of investigation chosen for this study limits the conclusions drawn to describe the collective, rather than the individual. That is, the results presented here do not describe one student's conceptions or reasoning, but the small group or class's reasoning. However, according to the theoretical frameworks of situated learning and the sociocultural perspective, student learning is situated within a social and cultural context. For this reason, analyzing collective discourse was appropriate for evaluating students' learning.

Further, comparison between two case studies, classroom A and B, allowed for identification of qualitative differences and similarities. These types of differences and similarities have implications for facilitation of discourse and student reasoning across many classrooms and disciplines. But the results presented in Chapter 4 and 5 are very specific to the sociocultural context from which they sourced. For this reason, the results are not generalizable.

Role of the Researcher

This study was housed in a larger research project, with the overall aim of investigating facilitation of the POGIL physical chemistry curriculum. Data was collected in the classroom by other members of the research team. My role in this project was to consider the content of the arguments generated as a result of students' engagement with

the POGIL curriculum. My detachment during data collection served to limit the influence of my personal biases on data collection. However, my biases became relevant during data analysis, manifesting themselves in critique of the instructor facilitation. To limit the influence of this bias, I engaged in ongoing conversation with the research team member who collected the data to ensure I understood the context in which data was collected and that my assessment was fair.

CHAPTER 4. DISCURSIVE DIFFERENCES BETWEEN CLASSROOM A AND B: EFFECT OF DIFFERING INSTRUCTOR FACILITATION STRATEGIES

Analysis of the arguments in each classroom yielded notable differences in discourse. That is, positive discursive moves that served to promote and further scientific discourse occurred more frequently in Classroom B, while negative discursive moves, serving to impede or limit discourse, occurred more frequently in Classroom A. There were patterns in students' use of causal reasoning across both classrooms, with a few differences between the two classrooms. Differences in instructional facilitation of argumentation serve to explain many of the similarities and differences in argumentation between the two classrooms. This chapter will include an overview of argumentation in both classrooms, comparison of discursive moves with positive and negative examples, examples of different types of causal reasoning, and a comparison of instructor facilitation.

Overview of Argumentation in Both Classrooms

Overall patterns in argumentation in each classroom will be presented to provide a context for comparisons between the two classrooms. There was a noticeable difference between the number of arguments generated in each classroom, as shown in Figure 4.1.

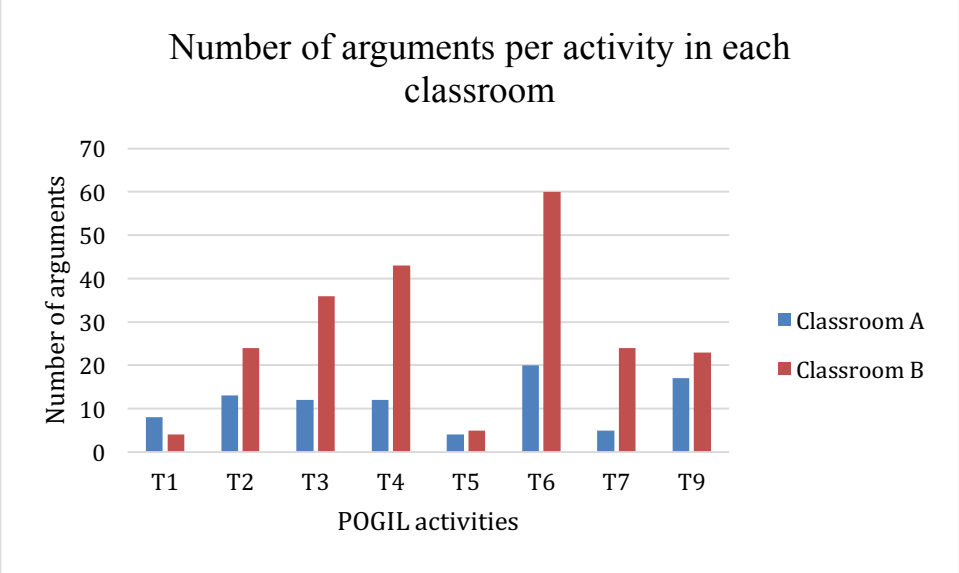


Figure 4.1 Comparison of the number of arguments generated in each classroom by POGIL activity

Classroom B largely outperformed classroom A in constructing arguments. Students in classroom B constructed a total of 219 arguments, while students in classroom A constructed 93 total arguments. Students in both classrooms constructed arguments that did not include a warrant (28/93 (30%) in classroom A; 34/219 (15%) in classroom B). These differences provide evidence indicating that generating arguments and justifying claims was more normative in classroom B than in classroom A. This difference is additionally supported by the comparison of discursive moves in each classroom, presented later in this chapter.

In addition to considering the number of arguments generated, this analysis evaluated students' use of scientific knowledge in constructed arguments. This evaluation serves to consider how physical chemistry students use thermodynamic content. The percentage of claims and warrants that used correct scientific knowledge according to activity for each classroom is presented in Table 4.1.

Table 4.1. Number of argument components that agree with scientific knowledge. Percentages are given in parentheses.

	Classroom A		Classroom B	
	Claim agrees with science	Warrant agrees with science	Claim agrees with science	Warrant agrees with science
T1: Work	8/8 (100)	6/6 (100)	4/4 (100)	4/4 (100)
T2: The first law of thermodynamics	12/14 (85.7)	1/1 (100)	18/24 (75)	20/21 (95.2)
T3: Enthalpy	10/13 (76.9)	10/12 (83.3)	29/36 (80.6)	25/34 (73.5)
T4: Heat Capacity	12/12 (100)	11/12 (91.7)	37/43 (86)	31/38 (81.6)
T5: Temperature dependence of the enthalpy of reaction	4/4 (100)	4/4 (100)	4/5 (80)	2/3 (66.7)
T6: Entropy	16/20 (80)	9/13 (69.2)	51/60 (85)	39/49 (79.6)
T7: Entropy changes as a function of temperature	4/5 (80)	5/5 (100)	15/24 (62.5)	10/15 (66.7)
T9: Gibbs energy and Helmholtz energy	12/17 (70.6)	9/13 (69.2)	15/23 (65.2)	15/21 (71.4)
Total	78/93 (83.8)	55/65 (84.6)	173/219 (78.9)	146/185 (78.9)

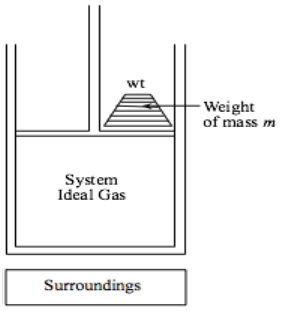
Students in classroom A included correct scientific knowledge in their arguments more than the students in classroom B. Classroom A also generated far fewer arguments. This difference in agreement with scientific knowledge is partially due to the nature of the arguments constructed in classroom A versus classroom B. In classroom A, students generally constructed arguments aimed at "getting the correct answer" to the given POGIL prompt; while in classroom B, students participated in the discursive practice of argumentation along with ultimately pursuing the correct answer. The differences in how students in each classroom participated in argumentation will be presented below.

Comparison of Discursive Moves

The Warrant

According to the Toulmin model, the warrant serves to explain how the data gives rise to the claim and has been cited as the most difficult component for students to generate (Bell, 2000; Mcneill, Lizotte, Krajcik, & Marx, 2006). This argument component is essential for exposing students' reasoning to their peers and the instructor. For this reason, when the warrant is unclear or irrelevant, the entire argument suffers from being unjustified. Further, in these instances, neither the instructor nor the peers are able to consider and evaluate an argument or students' understanding. In this way, a warrant that is unclear, irrelevant, or fails to connect the data to the claim, serves to inhibit discourse.

In classroom A, there were instances in which the warrant failed to connect the data to the claim. The following argument by Mark illustrates this type of warrant, generated in response to the POGIL prompt provided below.



Consider a situation in which the surroundings in Model 1 heat the system reversibly, causing it to expand. The position of the piston then increases by an amount ΔH. Is work done in this process? If not, why not? If so, is this positive or negative work?

Figure 4.2. Model 1 and corresponding POGIL prompt

Classroom A
Claim: Work sign is positive. (Mark)
Data: Model 1, page 52. (POGIL Materials)
Warrant: Work is being done by the system. (Mark)

In this example, Mark incorrectly claims that work is positive. It is true that work is done by the system in this model. However, his warrant did not use any information from the Model 1 information to make that claim, nor did it indicate an understanding of work. A more comprehensive warrant would have included that the piston height increase indicates that work was done, that the direction of height change indicates work was done by the system, and that the sign of work is assigned from the perspective of the system. In this case, the failure to connect the data to the claim is especially poor because it provides no insight into how Mark reasoned to arrive at the incorrect conclusion.

Warrants may also be weak due to lack of clarity or relevance. The following argument generated by Qi showing a derivation for an expression for change in entropy illustrates how an unclear warrant fails to support discourse.

Classroom A
Claim: dS = Cp/T dT -R/P dP (Qi)
Data: dH = dU +VdP + PdV (Qi)
Data: dH = CpdT (Qi)
Data: dU = TdS - PdV (Qi)
Warrant: So you just rearrange…It's just doing algebra with all the d stuff. (Qi)

A comprehensive understanding of the derivation would have manifested itself in descriptions of which substitutions and rearrangements led to the outcome. By arguing "you just rearrange", Qi did not provide any useful information to justify his claim. Additionally, the reference to "all the d stuff" indicates that the terms in the data equations were not being treated as values corresponding to thermodynamic concepts, but simply letters representing mathematical terms which needed to be manipulated. Though

the warrant is weak for these reasons, the claim is a correct mathematical output expected for this problem. This type of warrant hinders discourse by not exposing Qi's reasoning in such a way that his classmates and instructor A can consider and evaluate his argument.

Warrants in classroom B provide a contrast to the arguments generated in classroom A. In the following argument, Francis is arguing about work for the same process Mark considered in classroom A, but his warrant clearly connects the data to the warrant.

> **Classroom B**
> **Claim:** Work is negative when work is done by the system (Instructor/Francis)
> **Data:** Work is negative because pressure is lost (Francis)
> **Warrant:** Pressure is like force, so force was lost resulting in negative work (Francis)

This warrant sufficiently explains why work is negative when it is done by the system. Francis was describing work for a gas expanding in a piston-cylinder system. The whole argument, especially the warrant, is revealing of how Francis understands the concept of work, in terms of pressure. This discursive move equips Francis's peers and Instructor B to consider and evaluate his understanding, which can help move students towards a more productive scientific understanding.

In another example from classroom B, Reed and Jerome construct an argument describing an exothermic process, which includes a clear and relevant warrant.

> **Classroom B**
> **Claim:** Negative sign for enthalpy indicates that energy is given off (Jerome)
> **Data:** It is exothermic, bonds forming (Reed)
> **Warrant:** Bonds formed are more energetically stable than bonds broken, so you are in a more stable situation afterwards (Reed/Jerome)

In this argument, Jerome claims that a negative sign for enthalpy corresponds to a release of energy based on the data that bond formation is an exothermic process. To justify this, Reed and Jerome consider the perspective of energetic stability, explaining that "the bonds formed are more energetically stable than the bonds broken" and that this contributes to a release of energy, giving rise to the claim. Specifically, this warrant is able to serve its function of connecting the data to claim by being clear and relevant. Thorough warrants that connect the data to the claim support discourse in two ways. According to the framework of argumentation, the warrant serves the purpose of explaining how the data gives rise to the claim (Toulmin, 1958). To demonstrate competency in the practice of scientific argumentation, then, students must effectively develop and incorporate warrants. An explicit warrant allows the instructor and fellow students to evaluate each others' understanding to support building scientifically acceptable knowledge. A clear and detailed warrant is especially important for arguments in which the claim does not agree with scientific knowledge, as the warrant is the only way for others to understand how a student came to an incorrect conclusion.

The Rebuttal Targets Specific Argument Weaknesses

The rebuttal in an argument serves to question some aspect of an argument. Frequent occurrence of rebuttals in discourse is considered to be a sign of sophisticated argumentation (Erduran et al., 2004). Rebuttals indicate that students are considering each other's arguments, challenging each other's arguments, and generating counter-arguments. If a rebuttal is to effectively achieve these things, it must be specific, clear, and should target a weakness in a previous argument. In Classroom A, this was not

always the case. Rather, rebuttals aimed to provide correct arguments in response to previous incorrect arguments. Stephanie's rebuttal in the following argument exemplifies this.

> **Classroom B**
> **Claim:** ΔStotal has a positive sign. (Garrett)
> **Data:** (Stot)final = (Stot)initial (POGIL Materials)
> **Rebuttal Claim:** It is reversible. (Stephanie)
> **Rebuttal Data:** (Stot)final = (Stot)initial (POGIL Materials)
> **Rebuttal Warrant:** If the inequality applies the process is irreversible it will occur naturally. If the equality applies the process is reversible or at equilibrium. (Stephanie)

Garrett makes an incorrect claim based on the data. The total change in entropy is equal to the difference between the final and initial entropy, so if the data is true, then the total change in entropy should be equal to zero. With no warrant, it is not really possible to understand how Garrett justified his claim that the total entropy change would be positive. Because of this, it was expected that a fellow classmate would rebut his argument. Stephanie does so, but rather than questioning how Garrett reached his conclusion, she provides her own argument. She provides an argument that is correct in its use of scientific knowledge. According to the warrant, which came directly from the POGIL workbook, a process in which the final entropy change is equal to the initial entropy change is reversible. Though it is correct, Stephanie's rebuttal argument fails to rebut Garrett's argument as it does not target any weakness in Garrett's argument or answer the same question. Rebuttals that specifically target a weakness in an argument indicate that the listener is carefully considering the argument generated and it equips the arguer to evaluate their own argument.

The following argument from classroom A includes two rebuttals. The rebuttal argument provides an example of a rebuttal that does not specifically target a weakness in the previous argument, while Mark's rebuttal illustrates how a rebuttal may target a specific weakness.

> **Classroom A**
> **Claim:** the magnitude of work would increase (Jacob/Stephanie)
> **Data:** Model 1 - heating the system (book)
> **Warrant:** because more work is being done. Because the distance will change more (Jacob)
> **Rebuttal Claim:** the magnitude of work would decrease (Garrett)
> **Rebuttal Data:** Model 1 - heating the system (book)
> **Rebuttal Warrant:** gravity is negative (Garrett)
> **Rebuttal:** I think gravity would be positive in this case, because its weird just to have potential energy decrease. (Mark)

Jacob and Stephanie argue that the magnitude of work would increase for a process in which more heat was provided to the system by the surroundings. Jacob's warrant fails to explain how heating the system gives rise to more work. Garrett, rather than rebutting this weakness in the warrant, generates an alternative argument claiming the opposite, that the magnitude of work would decrease. Garrett warrants that the "gravity is negative", which appears irrelevant and fails to connect the heat change (data) to a work change (claim). However, Mark rebuts Garrett's argument by challenging his warrant, which was particularly weak. He explains that gravity would be positive as a potential energy decrease would not make sense. This rebuttal indicates that Mark is specifically considering Garrett's argument and responding accordingly.

In classroom B, the rebuttals showed that students were considering each others' arguments. This argument was generated in response to a prompt that asked students to

find the derivative of Helmholtz energy with respect to internal energy, temperature, and entropy.

Classroom B
Claim: dA=dU-TdS (Elliot)
Data: A=U-TS (given in book)
Warrant: Apply state function to data (Elliot)
Rebuttal: Why did T come out? Did you chain rule? (Jerome/Caprice)
Resolved claim: dA=dU-TdS-SdT (Jerome, Elliot, Caprice)
Data: dA=dU-d(TS) (Caprice)
Warrant: Use the chain rule (Jerome)

Elliot generates an incomplete equation for his claim, as it is missing a term (SdT). Elliot's warrant also suggests that he does not entirely understand the required mathematical operation. Jerome and Caprice rebut the claim by specifically challenging why the term was missing and which mathematical operation was used. This rebuttal is specific and targets the missing elements in Elliot's argument and it illuminates a possible misunderstanding about mathematical terminology. Namely, Jerome and Caprice ask Elliot if he used the chain rule, which is used to find the derivative of compositions of multiple functions. It is not appropriate for finding the derivative of the product of multiple functions, which is what was required to solve this problem. Jerome and Caprice's rebuttal suggests that they were critically listening to Elliot's argument, recognizing the weaknesses in his argument. In response to the rebuttal, all three students construct a new consensus argument. The new argument correctly includes the SdT term in the derivative, but incorrectly warrants the chain rule to justify the claim. The incorrect warrant in the consensus argument further supports the claim made earlier that a clear warrant has the potential to reveal when students' reasoning does not align with scientifically accepted knowledge (i.e. use of the chain rule). However, Jerome and

Caprice's rebuttal prompted Elliot to reevaluate his own argument and participate in consensus building.

One benefit of scientific argumentation is the opportunity for students to consider, weigh, and evaluate multiple arguments (Duschl, 2007). In order for students to become successful at this, they must be provided with criteria for evaluating arguments (e.g. the warrant serves to connect the data to the claim) and carefully consider each other's arguments in order to apply those criteria. The rebuttal reveals when a student recognizes and articulates an argument's shortcoming. The ability to generate a rebuttal that identifies and challenges weaknesses in an argument is crucial for participating in scientific discourse.

Rebuttals Contribute to Further Argumentation

One function of the rebuttal is to facilitate the construction and consideration of counter arguments. This means that episodes of sophisticated argumentation should involve multiple exchanges of arguments, rebuttals, and counter-arguments to engage students in generation and evaluation of multiple perspectives (Erduran et al., 2004). A negative rebuttal, then, would be one that serves to end the discussion without reaching a consensus. In the following example from classroom A, the students are trying to describe a spontaneous process.

> **Classroom A**
> **Claim:** Spontaneous means that it just happens. (Jacob/Mark)
> **Data:** Process occurs at standard conditions (Not ridiculously high or low temperatures or pressures). (Mark)
> **Rebuttal Claim:** Spontaneous process occurs without exterior interference. (Garrett)
> **Rebuttal Data:** It's happening entirely within the system. (Garrett)

Rebuttal Warrant: This means the process would not require external energy. (Garrett)
Rebuttal Qualifier: This can happen at any temperature. (Garrett)

Jacob and Mark argue that a spontaneous process is one that "just happens." They incorrectly draw from the data statement that this process must occur at standard conditions in order to make their claim. Spontaneous processes occur at specified conditions, but not necessarily standard conditions. In fact, in order to make a nonspontaneous process proceed, one must alter the conditions, which usually means using "ridiculously high or low temperatures or pressures." Unfortunately, there is no warrant provided, so it is difficult to understand how Jacob and Mark reached their conclusion from this data. Garrett responds with a rebuttal argument. Garrett is correct in claiming that a spontaneous process is one that "occurs without exterior interference" and that it can "happen at any temperature." This rebuttal argument also addresses the data used in the previous argument by specifically discussing the conditions. However, after Garrett singlehandedly generates this argument, the discussion ceases. Garrett's argument serves to provide the "correct" answer, but does not facilitate discourse in which all students participate in sense making. There is no evidence that Jacob or Mark considered Garrett's argument in light of their own. Had Garrett's argument resulted in a consensus argument, counter argument or rebuttal by Jacob or Mark, his rebuttal would have served as a positive discursive move.

The following argument sequence from classroom B illustrates the capacity of a rebuttal to further discourse. In this argument sequence, the students are trying to determine how to measure Cv, the heat capacity at constant volume.

Classroom B
Claim: A bomb calorimeter could be used to determine Cv. (Reed)
Data: By using a standard, then you know U.
Data: Bomb is constant volume (Reed)
Data: Cv equals [writes (du/dt)] (Reed/Instructor)
Warrant: so you can solve for the change for U, or the, you can solve for the U over dT, so you can solve for the change in energy with respect to temperature … {additional discussion} Because you're going to make the temperature change. And you know what your change in energy is, because you know how much energy you put in, and assuming you know how much it used, then you know much is used. (Reed)
Warrant: We use the bomb because that gives me the process at constant volume. (Instructor)
Request for clarification: How would you know how much energy you used? (Callum)
Clarification: Use standard mass to know how much internal energy there is. (Reed)
Rebuttal: you're not really accounting for base changes or difficult reaction processes. (Quentin)
Rebuttal Data: you're burning a substance so you're going to have combustion, you're going to be breaking down bonds and everything. (Quentin)
Rebuttal Warrant: So you're not really accounting for the molar heat capacity, isn't that just increasing the temperature of a substance by a certain amount? (Quentin)
Counter Claim: Apply a certain amount of energy to a substance and measure the temperature change [to determine heat capacity]. (Quentin)
Data/Warrant: You need to know how much of the substance you have (Quentin)
Data/Warrant: Assuming density doesn't change. He said the volume has to be constant. (Callum)

Reed and the instructor initially construct an argument claiming that a bomb calorimeter can be used to determine Cv based on evidence that a bomb maintains constant volume and measures energy, which provides the Cv value. Callum questions how this process can be used to calculate an energy change. Reed responds by claiming that using standard masses equips one to determine "how much internal energy there is." At this point, Quentin rebuts that this method of determining heat capacity does not account for "difficult reaction processes." He bases this off the data, which poses that when a

substance is burned, combustion occurs. He then reveals through his warrant that his understanding of heat capacity is the amount of energy necessary to raise the temperature of a substance and this does not align with what he thinks the initial approach (bomb calorimeter) would measure. Quentin poses a new claim, which argues that to determine heat capacity, one could "apply a certain amount of energy to a substance and measure the temperature change." In order for this to work, one must know the amount of substance being used. Callum rejoins the conversation, inputting that this process must occur at constant volume.

There are multiple positive discursive moves present in this episode. Callum's request for clarification indicates that he is trying to understand Reed and the instructor's argument. His reentry into the final argument indicates that he continued to engage the discourse and his provided warrant cites data from Reed's argument. Quentin's rebuttal argument is followed by a consensus argument generated with Callum. In this case, the rebuttal served to facilitate the generation of a counter argument, which is indicative of more sophisticated argumentation (Erduran et al., 2004).

Summary of Findings

The arguments presented above provide evidence of positive discursive moves found in classroom B and negative discursive moves present in classroom A. The positive discursive moves highlighted here are indicative of students' engagement in authentic scientific discourse. According to the theory of situated learning, when students demonstrate these discursive moves, they are recognizing and participating in the practices of the scientific community (Sadler, 2009). As argumentation is a central

practice of the scientific community, involving students in argumentative practices equips them to do science (Driver, Newton, & Osborne, 2000). This includes the ability to generate evidence-based claims with clear justifications; consider, weigh, and evaluate multiple arguments; defend arguments with counter arguments; challenge each others' arguments; and reach consensus (Driver et al., 2000). We identified instances of students demonstrating these competencies in classroom B. Students provided clear, explicit warrants that served to connect the data to the claim. They also rebutted arguments in such a way that indicated they were carefully considering arguments and contributed to further argumentation. The instructor plays an important role in promoting students' participation in this practice, which will be discussed in detail later in this chapter.

Use of Causal Reasoning

In addition to considering how students engaged in argumentative discourse, this analysis aimed to characterize the content of students' arguments. Specifically, students' arguments were used as artifacts for evaluating students' use of causal reasoning. That ability to reason with cause and effect mechanisms has been identified as a core scientific practice (National Research Council, 2012) . This is especially relevant in the context of chemical thermodynamics, which has the potential to answer "why" and "how" many chemical processes occur. To characterize how students employed causal reasoning, the modes of reasoning in the Chemical Thinking Learning Progression (CTLP) were used. Discussion of the different types of reasoning identified in each classroom and patterns in distribution of these types of reasoning will be presented here.

Descriptive Reasoning

Descriptive arguments did not contribute new information. Rather, they were repetitive, focusing solely on superficial features of the prompt.

Table 4.2. Descriptive argument generated in Classroom B in response to prompt to consider model reaction

POGIL prompt	Classroom B
The chemical reaction of A and B goes to completion: A(g) + B(g) —> C(g) + 2D(g) ΔrH=0 Before the chemical reaction occurs, what is the total number of moles in the container?	Claim: There are two moles of gas before the chemical reaction occurs (Elliot) Data: Model 2 information (book) Warrant: 1 mole of gas A and 1 mole of gas B (Rosalind)

Table 4.2 shows an example of a POGIL prompt eliciting descriptive reasoning. In this argument, the student is interpreting the reaction as listed in the problem. The student correctly identifies that one mole of A(g) and one mole of B(g) means that there are two moles of reactants. However, this argument indicates only consideration of explicit features of the problem, that is, the chemical reaction. This argument is not surprising, considering the prompt specifically asked the students to elaborate on what information the symbolic representation of the chemical reaction provides.

Table 4.3 shows the students in Classroom A and Classroom B making different claims, but using the same data and reasoning. It is clear that they are describing reactants in order to respond to the prompt. The claims they are generating rely on identifying reactants as molecules or elements as they are written. Similar to the previous example,

the question is prompting the students to describe features of the problem to make a claim. The prompt provides seemingly explicit conditions for identifying an enthalpy of formation reaction and yet the students from Classroom A and Classroom B do not generate the same claim. The practice of generating arguments revealed areas of possible confusion on the part of the students. Though it seems like they are not using complex reasoning or generating new information, the arguments they constructed to make descriptive claims reveal their reasoning and interpretation of the problem.

Table 4.3. Descriptive arguments generated in both classrooms in response to prompt to identify enthalpy of formation reactions

POGIL prompt	Classroom A	Classroom B
Mg(s) + CO(g) + O2(g) —> MgCO3(s) MgO(s) + CO2(g)—> MgCO3(s) Mg(s) + C(s) + 3/2 O2(g)—> MgCO3(s) BaCO3(s)—>BaO(s) +CO2(g) CO(g) + 1/2 O2(g)—>CO2(g) C(s) + O2(g) —> CO2(g) In which of the above reactions is the product the result of the reaction of the elements that compose it, each of the elements being in their stable states at 1 bar?	Claim: In reaction F, the product is the result of the reaction of the elements that compose it (Mark) Data: Model 4 chemical reactions (Mark)	Claim: C and F are a result of the reaction of the elements that compose it (Jerome/Jamal/Book) Data: Reactions from the book (book) Warrant: All the other reactions have molecules (Jerome/Jamal)

Relational Reasoning

The students in both Classroom A and Classroom B primarily used relational reasoning. Arguments using relational reasoning relied on a relationship without providing any sort of causal justification. Table 4 provides examples of this type of argument.

Table 4.4. Relational arguments generated in response to prompt to determine if pressure, volume, and enthalpy are state functions

POGIL prompt	Classroom A	Classroom B
Recall that energy, U, is a state function (or that dU is an exact differential). Is PV a state function? Is H a state function?	Claim: PV a state function (Garrett/Mark) Data: U is a state function (Mark) Warrant: Because it's a measure of energy, which is a state function (Garrett) Backing: The pressure is what it is, it doesn't matter what path the system took to get there. And the same with the volume (Instructor A)	Claim: H is a state function (Class) Data: H = U + PV (book) Warrant: It is a sum of state functions P, V, and U (Jake)

Excluding Instructor A's backing in Classroom A, student arguments took the form "If this variable is dependent upon another variable that is a state function, then it is a state function." Rather than considering the nature of enthalpy or internal energy in order to make claims about whether or not the variables were state functions, students exclusively considered the relationship between all the variables. Instructor A's backing inputs reasoning based on how pressure and volume change in a system in order to decide if they should be state functions. The backing provided by Instructor A illustrates a more complex causal model in which more thorough justifications indicating an understanding of pressure and volume are used to support the claim that pressure and volume are state functions.

In another example, Table 5 shows students' use of the relationship between the total entropy change and spontaneity of a system.

Table 4.5. Relational arguments generated in response to prompt to predict the spontaneity of a process

POGIL prompt	Classroom A	Classroom B
Imagine tossing a hot brick into cold water in an adiabatic enclosure. Assume that the resulting process does not affect the volume of the brick or the water. Can you determine the sign and/or magnitude of ΔStot for this process? If so, provide this information. If not, explain why not.	Claim: ΔS total for the process has a positive sign (Garrett) Data: because it is spontaneous (Garrett)	Claim: ΔS total is positive. (Callum) Data: because it's spontaneous (Callum) Warrant: Yeah, the change has to be spontaneous, ΔS system has to be spontaneous, so then the total has to be spontaneous. (Tice) Clarifier: So the total can't be spontaneous, the process can be spontaneous, but the math can't be spontaneous.(Instructor B)

In both iterations, students claimed that the total change in entropy would be positive for the process because the process is spontaneous. Instructor B aims to move students past only considering spontaneity and entropy change as mathematical values to considering them as variables that describe a process. Earlier arguments from this activity reveal that this justification is grounded in the definition for a spontaneous process provided in the POGIL information. Table 4.6 includes Jamal's argument when prompted to consider a process in which the final total entropy was larger than the initial total entropy.

Table 4.6. Relational argument in response to prompt to predict spontaneity of a process

Classroom B
Claim: Yes, the process is spontaneous (Jamal) Data: (Stot) final> (Stot) initial (Book) Warrant: That was part of the definition of spontaneous (Jamal)

Caprice uses the same reasoning for the reverse process, shown in Table 4.7.

Table 4.7. Relational argument in response to prompt to predict spontaneity of a process.

Classroom B
Claim: No the process is not spontaneous (Caprice) Data: (Stot) final<(Stot) initial (Book) Warrant: Because of the definition of spontaneous (Caprice)

All of these arguments draw on the relationship between spontaneity and total entropy change to justify claims. None of the arguments indicate an understanding of spontaneity, entropy, or the phenomenon (hot brick in cold water). There were no instances of students making sense of this relationship. This is partially due to the description of this concept in the POGIL curriculum in which a spontaneous event is defined as having a positive total entropy change. However, this indicates that Caprice and Jamal are simply quoting the POGIL text with no evidence of interpretation or sense making. More complex causal arguments would ideally incorporate reasoning about entropy and spontaneity, as well as the phenomenon at hand, to justify and predict an outcome. What these two arguments above suggest is that the relationship between spontaneity and total

entropy change was assumed to be sufficient justification for claims without a supporting explanation or interpretation.

Relational reasoning is particularly useful for revealing how students use relationships to justify claims. However, relational arguments often lack evidence of students' understanding of a certain relationship. More complex argumentation, including more robust warrants and more frequent rebuttals, can serve to prompt students to make explicit their understanding of scientific relationships.

Linear Causal Reasoning

Students in both groups demonstrated linear reasoning, which included some linear cause and effect mechanism. These arguments tended to take one of two forms, mathematical or conceptual. The structure of mathematical arguments usually included a linear, stepwise description of the mathematical operations students completed to move from the data, or initial equations, to claim, or final output.

Table 4.8. Linear arguments generated in response to prompt to complete a derivation

POGIL prompt	Classroom A	Classroom B
Show how $\Delta S_{\text{surr}} = \frac{\Delta H_{\text{surr}}}{T}$ can be obtained from $\mathrm{d}S = \frac{dq_{\text{rev}}}{T}$	Claim: ΔS=ΔH surr/T (Garrett) Data: dS=dqrev/T, dHsurr=dqsurr (Garrett/book) Warrant: So you have dS equals dq surroundings over temperature, and the equation you earlier, and since we just said in (9)a that dH surroundings equals dq surroundings, we can substitute that in. And then take a derivative I mean the integral (Stephanie)	Claim: Δ Ssurr is equal to delta H over T (Jamal) Data: ds = dqrev/T. T is constant, (Jamal) Warrant: And you pull that out and integrate so and integral of ds = 1 over T integral and dq. That gives you ΔS is equal to 1 over dq. And if dh is equal to q at constant pressure and temperature, then ΔS is equal to 1 over T ΔH. (Jamal)

The arguments in Table 4.8 show the sequential reasoning employed by the students to arrive at some mathematical product. In both cases, students list mathematical steps taken to complete the derivation. This is most frequently how students discussed any mathematical reasoning. This is noteworthy because one of the only times we see students use linear, stepwise reasoning with ease is when they are describing their mathematics. The burden to use linear reasoning is not a priority when explaining phenomena. In that case, relational reasoning without explanation is often considered sufficient.

There were instances of linear causal arguments for phenomena and concepts, but they did not follow as consistent of a structure as that observed in the mathematical arguments. In response to the prompt in Table 4.9 that required them to compare the final temperatures for neon and nitrogen upon the addition of the same amount of heat, Qi generated a linear argument to justify his claim.

Table 4.9. Linear argument generated in response to prediction prompt

POGIL prompt	Classroom A
Consider 1 mole samples of Ne and N2 at the same temperature T. Equal amounts of heat are added to each sample under otherwise identical conditions. Predict whether the final temperatures of the two samples will be the same or different. If different, predict which will have the higher final temperature. Explain clearly	Claim: Neon would have a higher temperature than N2 upon input of the same amount of energy (Qi) Data: It has like bonds (Qi) Warrant: So the bonds would absorb some energy (Qi)

Qi argues neon would have higher temperature exclusively from the perspective of nitrogen, explaining that because nitrogen has bonds that would absorb energy, it will have a lower temperature. It is important to note that there are features that are implicitly included in this argument. The reason that we can conclude that they are present is because they provide the connection between features that were made explicit (in contrast to relational reasoning where sequential reasoning was not employed and mechanistic steps were not made explicit). In order for Qi to draw the conclusion that he did, she had to assume that having more energy contributes to higher temperature. Providing a mechanism in an argument is revealing of steps the students thought important to verbalize and the steps that they assume are implicit.

Some linear arguments were a hybrid between mathematical and conceptual arguments. This hybrid type was particularly prevalent in arguments concerning Hess' law. Students in both groups used reasoning about the chemical process to inform how they completed the mathematical operation. These arguments still assume a linear description of steps taken to reach a mathematical output, but they include justifications grounded in the chemical process. Table 4.10 shows similar arguments generated in both classrooms to calculate the enthalpy change for vaporization of water.

Table 4.10. Linear arguments generated in response to prompt to consider the vaporization of water

POGIL prompt	Classroom A	Classroom B
Use these data [enthalpies of formation for gaseous and liquid water]and Hess' law to calculate ΔrH for the following reaction: H2O(l)—>H2O(g)	Claim: The ΔH of reaction is 44.01 KJ/mol (implied) Data: heat of formation reactions and ΔH values (book) Warrant: you add the reverse reaction, because you are going from H2 liquid to H2 gas, so you want to add the reverse (Stephanie)	Claim: ΔH for H2O(l)—> H2O(g) = difference between two heats of formation (44.01 kJ/mol) (Jerome/Quentin) Data: H2(g) + ½ O2(g) —>H2O(l) ΔrHo = -285.83 kJ/mol H2(g) + ½ O2(g) —>H2O(g) ΔrHo = -241.82 kJ/mol (Text) Warrant: The top equation needs to be flipped because you start with liquid water, flip it so the net equation would end with gas (Jerome/Liam) Backing: A positive value makes sense since you are vaporizing the water. (Liam/Quentin)

In the arguments presented in Table 4.10, students determine an enthalpy of reaction for the vaporization of water equaling 44.01 kJ/mol. Using Hess' law, they warrant switching the sign of the enthalpy of formation of liquid water and adding the enthalpy values to determine the total enthalpy change for the reaction. Particularly noteworthy in this argument is Liam and Quentin's explicit evaluation of the output value in which they rationalize the positive value based on the phenomenon. Students draw from the phenomenon to provide conceptual justifications for the mathematical steps taken to calculate an output value.

In another example of a hybrid structure argument, Instructor B builds on Sam's claim with a conceptual explanation, shown in Table 4.11.

Table 4.11. Linear argument generated in response to prompt to provide an equation

POGIL prompt	Classroom B
Use your answer to CTQ 8 and parts a and b above to provide an equation relating dUsys to pressure and volume for an adiabatic, reversible process.	Claim: dUsys = -PdV (Sam) Data: In an adiabatic system, dU=dq+dw, dq =0, dw=-PdV (CTQ8, 10a, 10b) Warrant: So for an adiabatic system where dq = 0, then the change in energy comes from changes due to work (Instructor B)

Instructor B explained the mathematical substitution (-PdV for dw in the first law equation) with a more conceptual description of the energy change sourcing from the work change. Instructor B was intentional about modeling how mathematical, linear reasoning is meaningful for understanding thermodynamic concepts. Linear arguments are distinct in their inclusion of cause and effect reasoning. In the arguments presented above, the students propose a mechanism in which one step (mathematical or phenomenal) leads to another and eventually an outcome.

Multicomponent Reasoning

Multicomponent arguments were the least frequent indicating the difficulty of considering multiple variables as contributing to an outcome. During the discussion of neon and nitrogen, two different groups from the Classroom B implementation generated multicomponent arguments shown in Table 12.

Table 4.12. Multicomponent arguments generated in response to prompt to predict temperature change for a process

POGIL prompt	Classroom B	Classroom B
Consider 1 mole samples of Ne and N2 at the same temperature T. Equal amounts of heat are added to each sample under otherwise identical conditions. Predict whether the final temperatures of the two samples will be the same or different. If different, predict which will have the higher final temperature. Explain clearly	Claim: Ne is hotter (Reed's board) Data: because neon is lighter. (Reed) Warrant: it'll move faster with the same amount of heat added. And because there's triple bond between nitrogen. The amount of heat given in the system, part of it will be considered to break the bonds. (Reed/Elliot)	Claim: Neon would be hotter than N2 (Quentin) Data: Neon doesn't have any bonds (Quentin) Warrant: Nitrogen has bonds, bonds can devote energy to stretching, straining, and you've also got rotational and those other types of motion. Whereas the Neon just has translational (Quentin)

In response to this problem, we see two different responses using multicomponent thinking. Reed concludes that neon would be hotter as it is lighter so it will move faster while nitrogen has bonds that heat will be used to break, so there is less energy to go into increasing temperature. The warrant that the heat added would break nitrogen bonds indicates an incorrect understanding of bond energies. However, he was correct in considering nitrogen's bonds and the difference in mass between nitrogen and neon as significant. Quentin's argument builds on Reed's by explicitly considering both neon and nitrogen, specific vibrational modes, rotational, and translational modes. Both of these arguments indicate that students recognize that multiple variables (i.e. mass difference, bond difference, etc.) give rise to neon ultimately having the higher temperature. The warrants in multicomponent arguments tend to be the most complete and thorough,

making consideration of multiple variables explicit. In the argument shown in Table 13, the students are considering entropy by discussing multiple facets of the concept.

Table 4.13. Multicomponent argument generated in response to prompt to predict entropy change for a process

POGIL prompt	Classroom B
As the temperature associated with the system is raised above 0 K, do you expect that the entropy of the system will increase or decrease? Explain your reasoning.	Claim: As temperature increases, entropy increases because of molecular movement (Jerome/Summer) Data: Definition of a solid is no molecular movement Warrant: Because the lower you go [temperature], the less movement there is (Summer) Backing: Because you have more distributed energy states (Thaddeus)

This argument provides evidence of students making sense of the concept of entropy by considering the definition of a solid, molecular motion, temperature, and energy states. Multicomponent arguments are especially complex, but are most apt for making sense of complex concepts such as entropy, which is inherently multifaceted. Because of this complexity, multicomponent arguments were by far the least frequent. These constitute quite sophisticated arguments, including thorough and complete justifications, in which students make their reasoning clear.

Summary of Findings

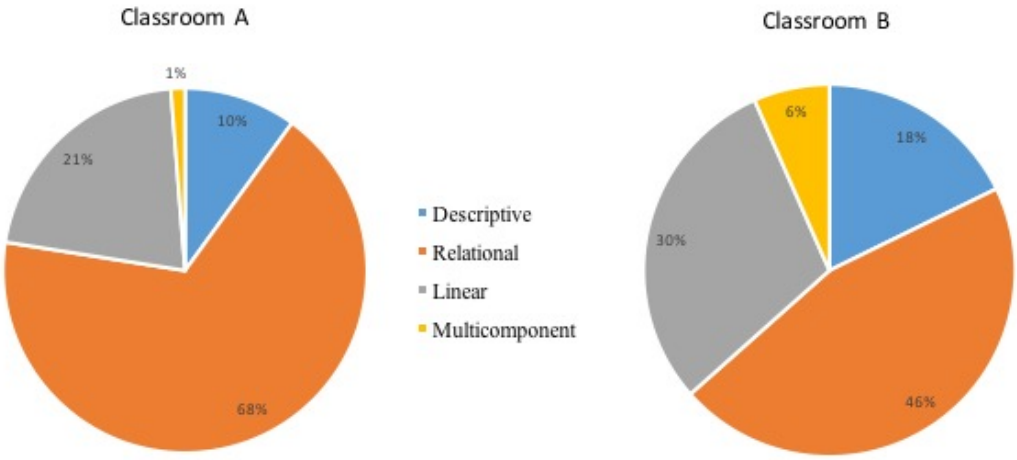


Figure 4.3. Overall distribution of modes of reasoning in each classroom

The overall distribution of reasoning is similar in each classroom in which relational reasoning is the most prevalent and multicomponent is the least prevalent, as shown in Figure 4.3. There were differences in the relative amounts of reasoning present in each classroom. The most noticeable difference is in the amount of relational reasoning (68% in classroom A and 49% in classroom). These differences are largely due to facilitation differences, which will be explored in the next section.

The results of this analysis demonstrate that students can construct arguments without necessarily including a causal mechanism. This counters what was expected based on previous work highlighting the usefulness of argumentation for prompting students to articulate their reasoning (Berland & Reiser, 2009). In this work, linear and multicomponent arguments that included evidence of cause and effect reasoning were more complete and thorough than the relational and descriptive arguments. That is, linear

and multicomponent arguments were indicative of students verbalizing more of their reasoning and understanding; whereas relational arguments included little evidence of the students' understanding of relevant concepts. This points to an important relationship between how thorough an argument is and the type of reasoning used. Generating an argument that is clear, coherent, and comprehensive often requires students to employ cause and effect reasoning to sufficiently justify a claim.

Analysis of Instructor Facilitation Differences

There were differences between the two classrooms in facilitation by the instructor with respect to how the class was structured and how the instructor participated in argument construction. The primary difference between how each class was structured was the use of whole class discourse and lecture. Classroom A time was split primarily between small group discourse, in which POGIL activities were covered, and lecture. In classroom B, time was primarily split between small group discourse and whole class discourse with very little lecture. Both small group and whole class discourse covered POGIL activities. Often, the whole class discourse covered the same critical thinking questions attempted in the small groups. Each small group would present the solutions they had generated to the whole class. This served to establish many positive argumentative norms in classroom B that explain the occurrence of the positive discursive moves. Specifically, by having each small group present their solutions, students were prompted to consider alternative arguments and work towards building a

consensus. Table 11 includes an example of a small group and whole class argument generated in response to the same POGIL prompt.

Table 4.14. Comparison of small group and whole class arguments generated in response to the same POGIL prompt

POGIL prompt	Consider 1 mole samples of Ne and N2 at the same temperature T. Equal amounts of heat are added to each sample under otherwise identical conditions. Predict whether the final temperatures of the two samples will be the same or different. If different, predict which will have the higher final temperature. Explain clearly
Small group	Claim: Neon would be hotter that N2. (Summer) Data: Neon doesn't have any bonds. (Summer) Warrant: Nitrogen has bonds, bonds can devote energy to, stretching, straining, and you've also got rotational and those other types of motion. Whereas the Neon has just translational. (Summer)
Whole class	Claim: The N2 will be hotter? (Quentin board) Data: Kinetic energy = 1 times mv squared, and N2 weighs more than neon. (Quentin) Warrant: That if it weighs more, it's going to have a slower velocity. And since the term's v squared, and in that sense, we figure that the velocity would have more weight than the temperature. (Quentin) Alternate Claim: Ne is hotter. (Dominique's board) Alternate Data: Neon has less intermolecular forces. (Dominique) Alternate Warrant: So more the heat would be going towards kinetic energy. (Dominique) Alternate Claim: Ne is hotter. (Reed's board) Alternate Data: Because neon is lighter. (Reed) Alternate Warrant: It'll move faster with the same amount of heat added. And because there's triple bond between nitrogen. The amount of heat given in the system, part of it will be considered to break the bonds. (Reed/Sam) Rebuttal: Oh, just because I heat up nitrogen gas, does it disassociate the bonds? (Instructor B) Alternate Claim: Neon is hotter. (Jerome's board) Alternate Data: With the N2, now you have different ways for it to move, plus devote energy towards the bond, be it vibrational, rotational versus not just translational movement and stuff. (Jerome) Alternate Warrant: There are other ways to devote heat to it, it doesn't necessarily have the same increasing kinetic energy for that kind of input. You'd have more if your input of energy towards translational movement of the neon, so it was up for hotter average kinetic energy and hotter. (Jerome)

The arguments in Table 4.14 illustrate the potential of whole class discourse to expose multiple students' reasoning. In the whole class argument sequence, multiple data and warrants are generated to justify the claim that the neon would be hotter (i.e. "neon is lighter," "nitrogen has a bond," and "neon has less intermolecular force"). Only one of these was provided in the small group argument (i.e. "neon doesn't have any bonds"). By engaging students as a whole class after they had worked in small groups, the instructor prompts the students to consider each other's argument. This instructor facilitation choice also serves to implicitly place an emphasis on reaching consensus, which is evidenced in classroom B's discursive move of using rebuttals to further discourse and reach consensus.

Another difference between the classrooms that contributed to a difference in argumentation quality was the expectations set forth by the instructor. Instructor A explained to his students the function of small group work and the roles each student was to assume (i.e. manager, presenter, recorder, technician, and reflector). He did not provide any explicit instruction about argumentation; that is, what constitutes an argument or what makes an argument good. In not doing so, Instructor A did not set forth the expectation for students to construct arguments in the classroom. In contrast, Instructor B explicitly introduced the Toulmin model, explained each component, and thus set forth the expectation that students use it engage in discourse with each other.

In addition to course structure differences between the two classrooms, there were differences in how the instructors interacted with students and participated in constructing arguments. Instructor B engaged in discursive moves that were relatively absent in classroom A. Instructor B explicitly modeled rebuttals. Though Instructor B

questioned and challenged students more frequently in the whole class discourse, she maintained a presence while students worked in small groups. The following argument was constructed in small group while working through activity T6 on entropy.

> **Classroom B**
> **Claim:** Irreversible processes are spontaneous. (Jerome)
> **Data:** Cause that would be your Δ S universe is greater than or equal to zero. Or greater than zero (Jerome)
> **Rebuttal:** Does it have to be spontaneous? (Instructor B)
> **Claim:** No. An irreversible process does not have to be spontaneous. (Brittany)
> **Warrant:** All spontaneous processes are irreversible, but not all irreversible processes are spontaneous. (Instructor B/Jerome).

In this argument, the instructor performs all three positive discursive moves that were identified in classroom B's discourse. Instructor B rebuts Jerome's claim "Irreversible processes are spontaneous" by challenging the generalization of his claim. Her rebuttal is specific and targets the weakness of Jerome's argument. In response to her rebuttal, Brittany claims that "An irreversible process does not have to be spontaneous." Instructor B's rebuttal made space for Brittany to enter, resulting in construction of a consensus argument. Finally, the warrant constructed by both Instructor B and Jerome was clear and explicit. There was no data provided, so it is impossible to evaluate how well the warrant connected the data to the claim.

In classroom A, arguments co-constructed between the instructor and student occurred less frequently than in classroom B. It is believed that this practice of co-constructing arguments with students serves to model effective discourse, which results in students incorporating those discursive moves into their own discourse. The following example illustrates how Instructor B modeled a quality backing. In this argument, students are attempting to obtain an expression for dH in terms of Cp.

Classroom B
Claim: dH = CpdT (Dominique)
Data: dH = ∂H/∂T)P dT + ∂H/∂P)T dP (Dominique)
Data: Cp = ∂H/∂T)P (Dominique)
Warrant: Pressure is constant, so second term goes to zero. (Dominique)
Warrant: And then substitution. (Dominique)
Rebuttal: You don't need the subscript P for Cp. (Caprice)
Rebuttal Claim: You do need to indicate the constant pressure process. (Male)
Rebuttal Data: It is not a state system. (Male)
Rebuttal Warrant: Because it's, it's the heat capacity at a constant pressure, so, and that's how you're denoting it, that's what the Cp equals. (Dominique)
Rebuttal Backing: And since Cp and Cv are not equivalent, you have to know under what conditions the heat capacity arises. (Instructor B)

Dominique correctly derives the expression. Caprice rebuts that "You don't need the subscript P for Cp." Another student enters the conversation and argues that you do need the subscript because that it is a constant pressure process. Instructor B adds a backing that helps to contextualize the problem, thus giving the warrant more authority. She distinguishes between Cp and Cv and clarifies that it is important to understand the conditions under which heat capacity arises. Instructor B models the use and function of a backing, which contributes to students' understanding of the Toulmin model and tendency to incorporate it into their discourse.

A final instructor discursive move present in classroom B was explicit eliciting of explanations and justifications. It is believed that this contributed to the higher percentage of arguments including a warrant (85% in classroom B, 70% in classroom A) and the higher percentage of causal reasoning (30% linear causal and 6% multicomponent in classroom B, 21% linear causal and 1% multicomponent in classroom A). The following excerpt from classroom B's class transcript illustrates how explicitly Instructor B elicited explanations.

Jerome: So your next line is DU minus T(dS) minus SdT, you got to add the minus SdT to the end, for your chain rule.
Dominique: Okay, yeah, I'll erase this.
Jerome: Just add to it, just add a minus SdT, that's good.
Dominique: That makes sense.
Instructor B: You need the last equation; why do you need the last equation, why can't you just leave it dTS?
Caprice: Because you don't need (inaud) the next one.
Instructor B: True, but.
Jerome: You, because that's the expanded version of the equation, you have to use the product rule.
Instructor B: Right, you want to actually take out the product, if you use the product rule, you need the whole thing. It's more usable in that case, unless you're going to substitute in for TS, and are we substituting in for TS here?
Instructor B: No, okay, so continue on.
Dominique: Okay, so then it tells us to find for constant temperature, so then basically this is going to be 0, we're going to end up with that (dA = dU-TdS). everybody agree?
Class: Yeah, okay.
Instructor B: You make a claim, then explain it, why is that last term essentially going to be 0?
Dominique: Because there's no change in temperature, so dT is here.
Instructor B: Will it essentially be 0?
Dominique: It will be, sorry. And then it's asking how total work is related to delta A of a constant temperature process? And we know that, actually I don't really know this one. I know I did it wrong from the beginning. Do you have it?
Rosalind: I have to write it out before I attempt explain.
Instructor B: You need to explain while you're writing. You can write a line and then explain it, but don't do the whole thing out.

Instructor B first enters the conversation to question Dominique and Jerome with “why do you need the last equation; why can’t you just leave it dTS?” This instructor move of asking why is effective for eliciting further justification or prompting students to reflect on their claims and strengthen their explanation. Instructor B supports this move with explicit instruction about how to present solutions to the class when she says “you make a claim, then explain it, why is that last term essentially going to be 0?” Finally, Instructor B provides explicit instruction exclusively on how to present solutions to the classroom in such a way that supports argumentation when she responds to Rosalind. She states that

"you need to explain while you're writing. You can write a line and then explain it, but don't do the whole thing out." Explicit instructions about how to participate in the practice of scientific discourse supports students' abilities to participate in that practice. This is evident in classroom B's increased number of arguments, warrants, and improved causal reasoning.

Summary of Findings

The instructors of the classrooms observed in this study chose different facilitation strategies. These differences gave rise to differences in the students' argumentation in each classroom. Specifically, the students in classroom B generated more arguments, included more warrants that were specific and clear, engaged in consideration of counterarguments and consensus building, and employed more complex causal reasoning. It is believed that there were specific instructor facilitation differences gave rise to the positive discursive moves seen in classroom B. These are highlighted in Table 4.15.

Table 4.15. Differences between each classroom's argumentation explained by instructor facilitation moves

	Classroom A	Classroom B	Instructor moves to facilitate positive moves
Warrant	Unclear, uninformative Does not connect data to claim	Clear, detailed Connects data to claim	Instructor explicitly elicits explanations/justifications to promote warrant construction
Causal Reasoning	More descriptive and relational reasoning	Linear causal and multicomponent reasoning	
Rebuttal	Substitutes "correct answer"	Questions specific weakness in an argument	Instructor models argumentation by contributing argument components
	Impedes further argumentation	Promotes further argumentation Contributes to consensus building	Use of whole class discourse following small group discourse

The differences observed in each classroom point to each classroom's values. In classroom A, students generated fewer arguments and demonstrated fewer positive discursive moves with an emphasis on getting the right answer. The instructor largely influences the quality of resulting classroom discourse. However, there were themes in discourse across both classrooms that resulted from the curriculum. The analysis investigating this relationship will be presented in the next chapter.

CHAPTER 5. ANALYSIS OF THE POGIL CURRICULUM USING TASK ANALYSIS GUIDE FOR SCIENCE

Classroom A and B both used the POGIL thermodynamics curriculum. For this reason, the curricular materials serve to explain some of the similarities observed in both classrooms' argumentation. Two dimensions of the POGIL curriculum were considered. The first was the overall organization and structure of the POGIL curriculum. The second was the individual prompt types. The effect of both of these dimensions on students' argumentation was analyzed. Process-oriented guided inquiry learning is intended to facilitate the construction of both content knowledge and process skills (Moog et al., 2006). For this reason, the Task Analysis Guide for Science (TAGS) was chosen as a means of evaluating the POGIL curriculum for its targeting of both content and practices, as outlined by the NGSS (Tekkumru-Kisa et al., 2015). This chapter will include an overview of the TAGS framework used to analyze the curriculum, an overview of the curriculum, and a discussion of the relationship between POGIL structure and prompt type and resulting argumentation.

Task Analysis Guide for Science

Use of TAGS

Table 5.1. Task analysis guide for science, reproduced from Tekkumru-Kisa, Stein, and Schunn (2015)

Cognitive Demand Levels

		Scientific Practices (e.g., argumentation and investigation)	Science Content (i.e., scientific body of knowledge)	Integration of Content and Practices
5	Doing Science Tasks			**Doing Science (DS)** Engaging in practices to make sense of content and recognize how scientific body of knowledge is developed
4	Tasks involving guidance for understanding			**Guided Integration (GI)** Guidance for working with practices tied to a particular content
3		**Guided Practices (GP)** Being guided for understanding practices	**Guided Content (GC)** Being guided for understanding particular content	
2	Tasks involving scripts	**Scripted Practices (SP)** Following a script to work on practices	**Scripted Content (SC)** Following a script about a content	**Scripted Integration (SI)** Following a script to work on practices tied to content
1	Memorization tasks	**Memorized Practices (MP)** Reproducing definitions/explanations of practices	**Memorized Content (MC)** Reproducing definitions, formulas, or principles about particular content	

Table 5.1 provides the task analysis guide for science, as reproduced from Tekkumru-Kisa, Stein, and Schunn (2015). To assign a TAGS label to a prompt, multiple features including context, placement in the activity, and information provided were all taken into consideration. Placement in the activity and information provided were especially important for delineating cognitive demand levels. For example, if the students had already derived all relevant equations before the prompt, the prompt would tend to be scripted. In contrast, if the prompt is the first in an activity and requires the generation of new information, it more likely to receive a guided label. Generally, cognitive demand was assigned according to the following criteria (Tekkumru-Kisa et al., 2015).

Table 5.2 Interpretations of cognitive demand levels used to code POGIL prompts

Cognitive demand	Interpretation used for coding
Doing Science	Requires students to engage in scientific practices and scientific knowledge construction relatively unaided
Guided	Requires the generation of new knowledge, information, practice
Scripted	Requires students to follow a script to complete
Memorized	Requires students to regurgitate provided information

To distinguish between practices, only what was explicitly elicited in the prompt was considered. For example, a prompt must tell the students to generate a question in order to be targeting the ‘asking questions’ practice. In considering prompts which were difficult to categorize for the primary researcher, feedback was sought from other chemistry education researchers. The primary researcher assigned labels to those prompts

in accordance with the feedback received. Tables 5.3 and 5.4 provide examples of POGIL prompts corresponding to each cognitive demand level and scientific practice.

Table 5.3. Examples of POGIL prompts corresponding to each cognitive demand level

Cognitive demand level	POGIL prompt
Doing Science	
Guided	Is there a generalization of the use of enthalpy of formation data to calculate ΔrH° for a chemical reaction? If so what is it?
Scripted	Calculate the work done in an expansion against zero pressure.
Memorization	What is the relationship, at all times, between Pex and Pint for a reversible process?

Each of these examples require some context to understand the assignment. For the example of a memorization task, a reversible process was defined for students as a process with external pressure equal to internal pressure at all times. As students simply needed to repeat the definition provided to them to complete this task, it was assigned a memorization level. In the case of the scripted prompt, the equations to calculate work had been provided to the students, but they did have to execute the calculation to output a solution, which warranted a scripted label. Before the guided prompt, the students had considered enthalpy of formation data to explain chemical reactions. But they had not generated a model to use that data, which is what warranted this a guided label.

Table 5.4. Examples of POGIL prompts corresponding to each science practice

Scientific Practice	POGIL prompt
Asking Questions	
Developing and using models	Is there a generalization of the use of enthalpy of formation data to calculate ΔrH° for a chemical reaction? If so what is it?
Planning and carrying out investigations	Design an experiment to determine the heat capacity of a substance for a constant volume process
Analyzing and interpreting data	Based on the data in Table 1, what is the molar heat capacity of Ne(g)?
Using mathematics and computational thinking	Provide an expression relating the infinitesimal work, dw, to the force, f, and the infinitesimal distance, dl. Make sure that the sign convention described above is followed.
Constructing explanations	Use your knowledge of the temperature dependence of C°P to explain why ΔrH° varies with temperature.
Engaging in argument from evidence	Critique the following statement: The more complex the species, the larger is $\bar{C}$°p and the larger the increase in $\bar{C}$°p with increasing temperature. Refer to Table 4.
Obtaining, evaluating, and communicating information	Without reference to entropy, use a grammatically correct English sentence to describe what it means to indicate that a particular process is "spontaneous."

The practice of 'asking questions' was not targeted explicitly in the POGIL thermodynamics curriculum. Of the practices that were targeted, 'developing and using models' and 'Obtaining, evaluating, and communicating information' were the most difficult to identify. The example provided for the practice 'developing and using models' requires students to build a model for calculating enthalpies of reaction. It explicitly elicits the development of models by asking the students to form a generalization. The example provided for 'obtaining, evaluating, and communicating information' requires students to define a spontaneous process. However, the prompt is explicit in its requirements for how to communicate the definition.

Overview of Curriculum

The POGIL curriculum overwhelmingly engages students in scripted tasks, which means a majority of prompts require students to follow a clear set of steps to complete the task. Most of the prompts target the integration of both content and practices, as seen in Figure 1. There were no tasks that targeted only a scientific practice at any cognitive demand level.

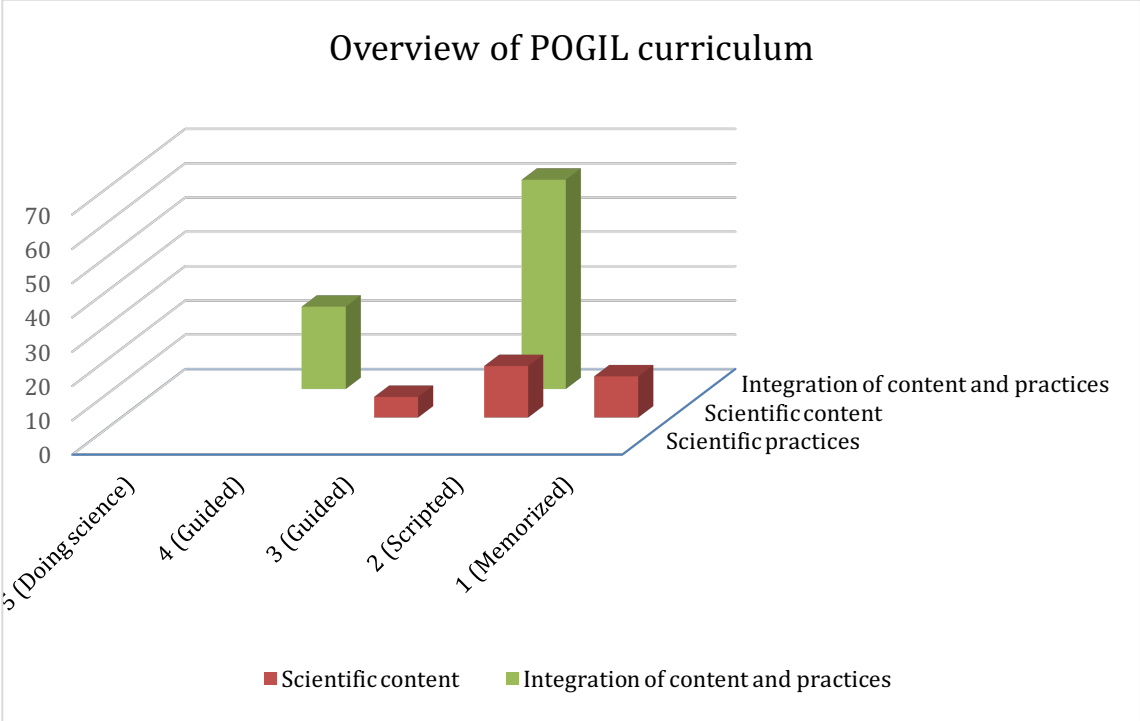


Figure 5.1. Overall distribution of types of POGIL prompt as categorized by TAGS.

The trend observed in Figure 5.1 varied slightly with content. As seen in Figure 2, every activity except for T5 primarily involve scripted integration tasks. The activity T5, which targets the temperature dependence of enthalpy of reaction, is short with only six prompts, most of which are guided. The activities T4 and T7, heat capacity and entropy

changes as a function of temperature, include more guided integration tasks. Activity T9, Gibbs energy and Helmholtz energy, has an equal number of scripted content and scripted integration tasks, which means that this activity does not require students to engage in scientific practices to complete many of the tasks.

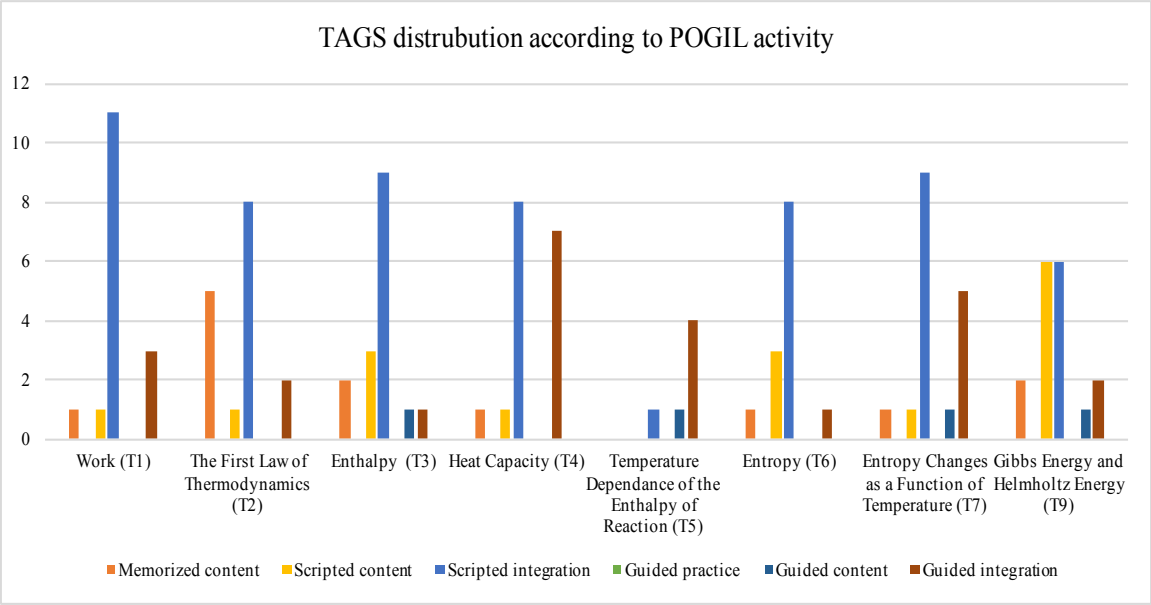


Figure 5.2. Distribution of POGIL prompt type for each activity

Figure 5.1 and 5.2 indicate that not all prompts target a practice (i.e., SC, MC). Of the prompts that targeted a practice (i.e., GI, SI), 'using mathematics and computational thinking' and 'constructing explanations' are the most frequently targeted by the POGIL Thermodynamics curriculum, which is shown in Figure 5.3. Prompts targeting 'using mathematics and computational thinking' required students to perform a mathematical operation or calculate an output. Prompts targeting 'constructing explanations' explicitly

asked students ‘why’ or instructed them to ‘explain their reasoning.’ There were prompts that targeted multiple practices. For example, a prompt that directed them to complete a mathematical operation and then explain their output targets both ‘using mathematics and computational thinking’ and ‘constructing explanations.’

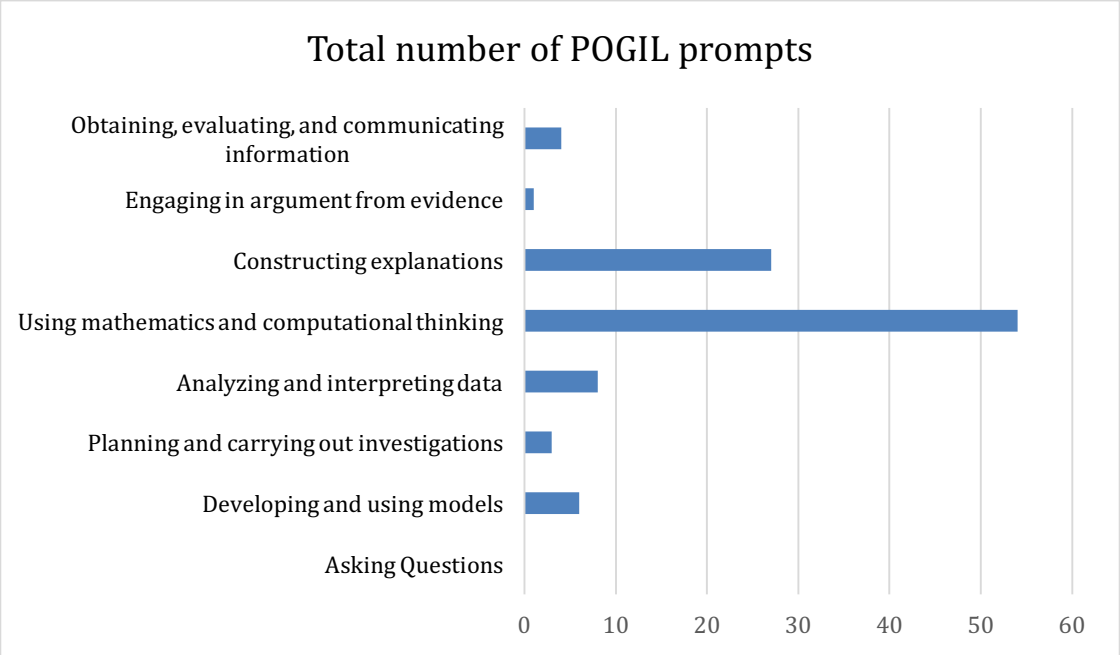


Figure 5.3. Distribution of scientific practices targeted by POGIL curriculum

This trend of primarily ‘using mathematics and computational thinking’ and ‘constructing explanations’ varied slightly across activities, which is shown in Figure 5.4. Activities T2, T3, and T9 almost exclusively target the practice of ‘using mathematics and computational thinking’ with very little explicit elicitation of explanations. Activity T6, entropy, was unique in eliciting explanation more than using mathematics and computational thinking.

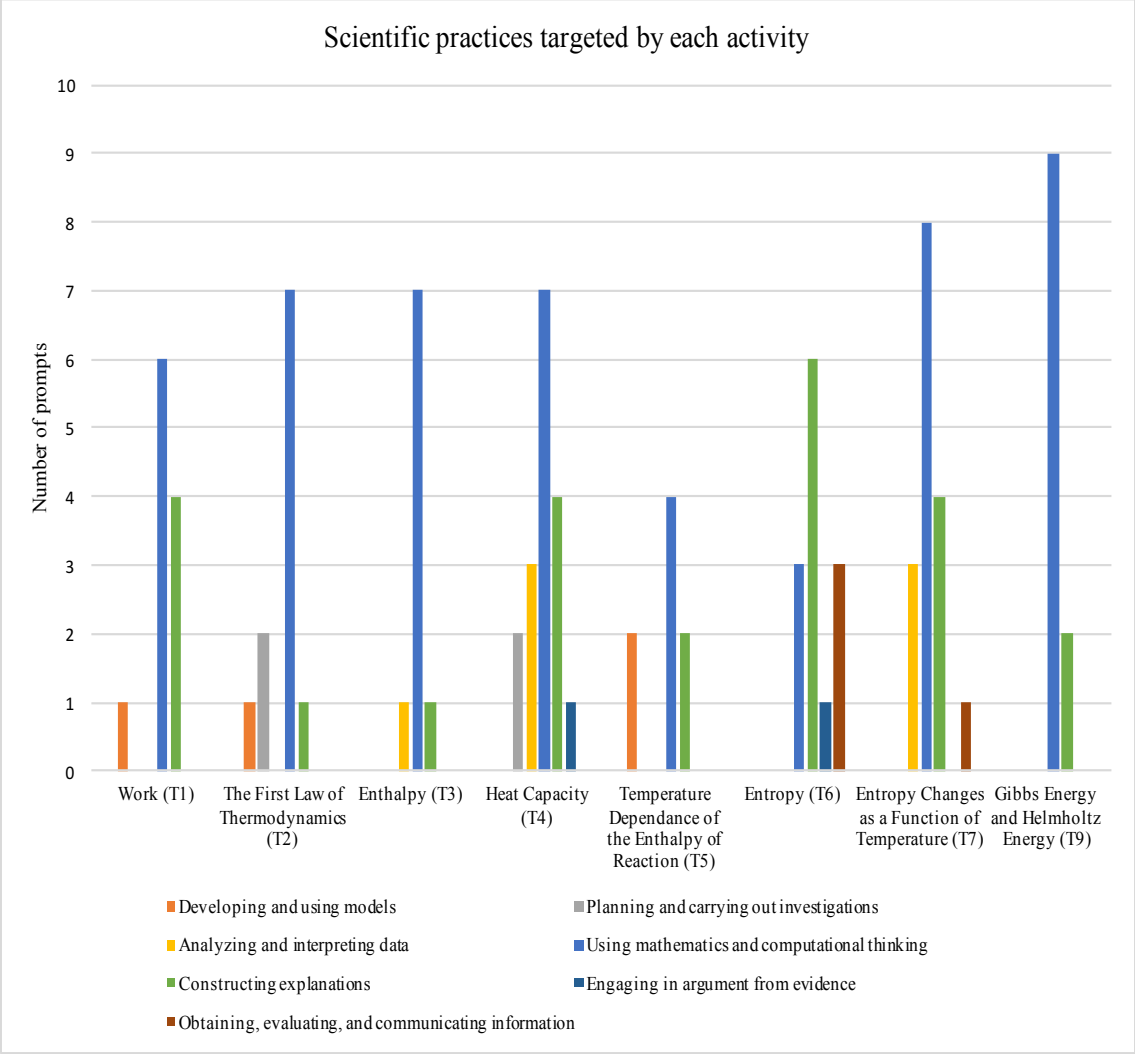


Figure 5.4. Distribution of scientific practices for each activity

The POGIL Thermodynamics curriculum overwhelmingly uses scripted integration tasks and targets the practices of 'using mathematics and computational thinking' and 'constructing explanations.'

Effect of TAGS Label on Number of Arguments

There were multiple factors that influenced the quantity and quality of arguments resulting from the POGIL curriculum. The factors that will be considered here are the content, the practices being targeted by prompts, and the cognitive demand of prompts. Figure 5.5 shows how the number of arguments varied with thermodynamics content associated with activities T1 through T9.

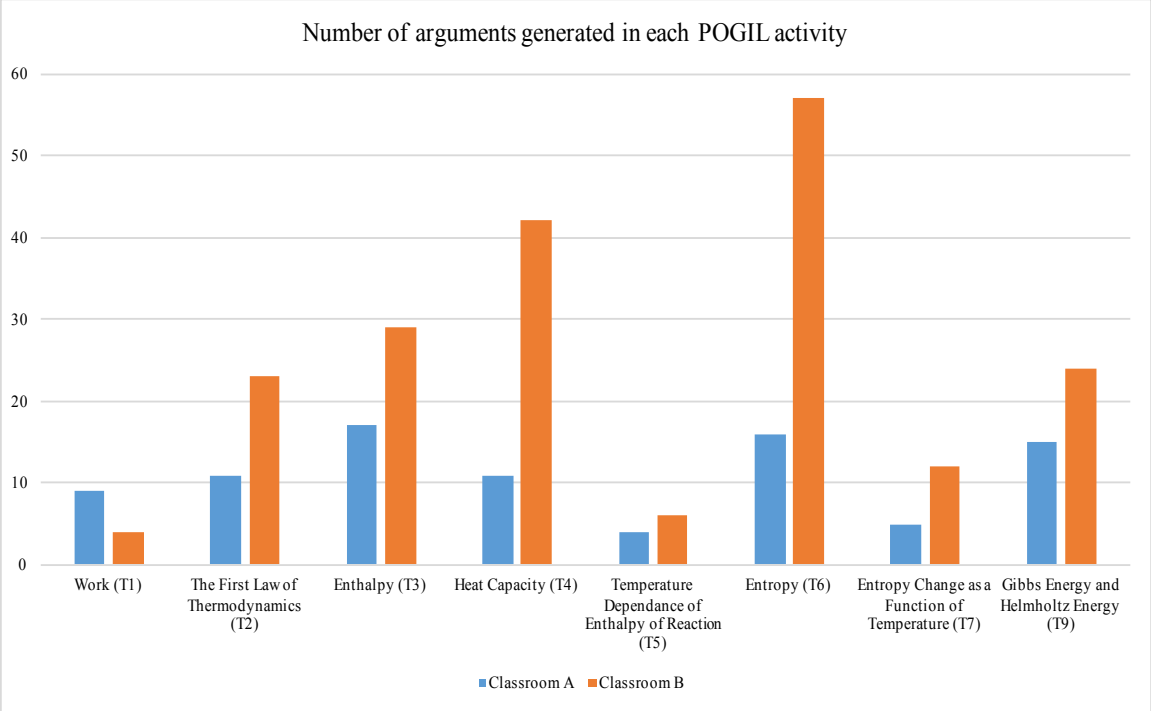


Figure 5.5. Number of arguments generated during each activity

The overall pattern between the two classrooms is similar. For both classrooms, Activities T1, T5, and T7 resulted in the fewest arguments. In order to identify trends in the relationship between the POGIL curriculum and the resulting arguments, the TAGS framework provides categorization of POGIL prompts according to cognitive demand and science practices being targeted. Results show that the scientific practice being targeted impacts the number of resulting arguments, while cognitive demand has less of an impact. Table 5.5 shows the number of arguments resulting from each scientific practice. Prompts that explicitly require students to construct explanations generate more arguments. Other practices (i.e. developing and using models, analyzing and interpreting data, and engaging in argument from evidence) also showed to result in more arguments. There were fewer prompts that targeted these practices, however, making them difficult to compare to 'using mathematics and computational thinking' and 'constructing explanations.'

Table 5.5. Number of arguments resulting from each scientific practice

Scientific Practices	Number of prompts	Number of arguments	Arguments/ prompt
Engaging in argument from evidence	1	5	5
Constructing explanations	20	85	4.25
Developing and Using models	6	19	3.2
Analyzing and interpreting data	6	19	3.2
Using mathematics and computational thinking	39	115	2.95
Planning and carrying out investigations	2	5	2.5
Obtaining, evaluating, and communicating information	2	4	2
Asking Questions	0	0	0

Cognitive demand and integration of practice and content have less of an impact on the number of arguments generated.

Table 5.6. Number of arguments resulting from prompts with each TAGS label

TAGS	Total prompts (TP)	Arguments generated	Arguments/ TP
Memorized content (MC)	12	6	0.5
Scripted content (SC)	15	37	2.47
Scripted integration (SI)	61	127	2.08
Guided content (GC)	6	17	2.83
Guided integration (GI)	24	46	1.92

Table 5.6 shows that of the prompts that elicit arguments, scripted content arguments elicit more arguments than any other TAGS labels. Table 5.5 indicates that the scientific practice being targeted has a larger impact on the number of arguments generated overall. The distribution of targeted practices across activities, shown in Figure 5.4, then serves to partially explain the distribution of number of arguments across activities, which is observed in Figure 5.5.

Arguments Resulting from Prompts Targeting Different Practices

There were differences in the types of arguments resulting from prompts targeting different practices. These differences in the nature of the arguments serves to support how targeting certain practices elicits more arguments. For example, the following prompt requires students to consider a hypothetical process for a model provided

(developing and using models) in order to make sense of the First Law of Thermodynamics, which is shown in Figure 5.6.

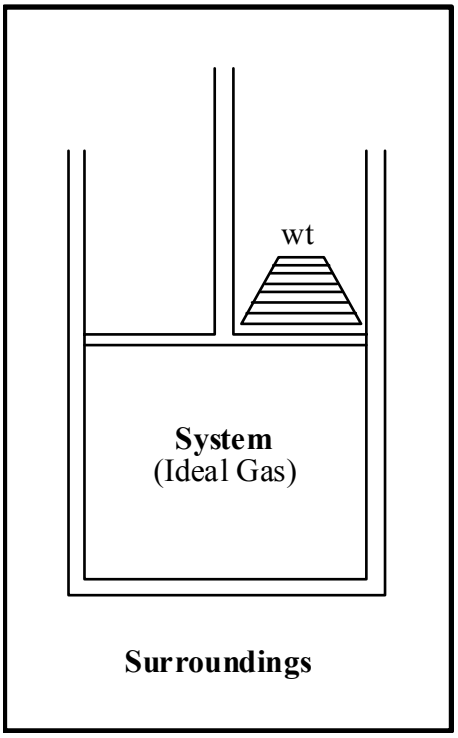


Figure 5.6. Model 1 in Activity T2 in the POGIL:Thermodynamics curriculum

Consider a situation in which the surroundings in Model 1 heat the system reversibly, causing it to expand. The position of the piston then increases by an amount Δh.

a) Is the external pressure constant for this process?
b) Is the pressure of the system, the internal pressure, constant?
c) Laboratory experiments are usually not carried out in a piston-cylinder with a weight attached, but in open vessels. What is the external pressure source in these experiments?

In response to this prompt, the students in both classrooms generated arguments in response to part or all of the prompt.

Classroom A
Claim: External pressure stays the same. (Mark/Garrett)
Data: Weight is not changing. (Garrett)
Warrant: The weight is going to be the source of the pressure. (Garrett)

Claim: Internal pressure is not constant. (Stephanie)
Data: Volume is changing. (Stephanie)
Warrant: The pressure is still increasing. (Stephanie)

Classroom B
Claim: External pressure is constant for the process. (Aiden)
Data: System is reversibly changing. (Aiden)
Data: Volume is changing. (Aiden)
Rebuttal: Those are true statements, it does not lead me to believe that it's constant external pressure though. (Instructor B)
Data: Atmospheric pressure (1 atm) is constant. (Aiden)
Warrant: So if you are doing it against atmospheric pressure, the atmospheric pressure will not change if you heat the system. (Aiden/Instructor B)

Claim: The pressure of the system is constant for the process. (Aiden)
Data: The system is reversible. (Aiden)
Warrant: So the total energy is constant. (Aiden)
Rebuttal: That's true, but it doesn't have anything to do with… (Instructor B)
Warrant: Because the system is in equilibrium. (Aiden)
Backing: That's what "reversible" means is the system is in the equilibrium throughout the process. If it's in equilibrium, then the internal pressure and my external pressure have to be equivalent. (Instructor B)

In response to this prompt, all of the arguments draw on data provided in the model given in the prompt. In classroom A, Stephanie, Mark, and Garrett ground their claims in the data statements that the "weight is not changing" and the "volume is changing." In classroom B, Aiden draws on the "system is reversibly changing" and "volume is changing." All of the arguments describe a phenomenon and use conceptual reasoning.

Prompts targeting 'using mathematics and computational thinking' elicited very different arguments that included less conceptual reasoning. The following prompt specifically asks students to derive an expression.

Let dU=CvdT and rearrange equation (4) [dU=TdS – PdV] to provide an expression for dS for one mole of an ideal gas in terms of T, V, and Cv.

In response to this prompt, students generated linear causal, mathematical arguments.

> **Classroom A**
> **Claim:** dS=CvdT + PdV
> **Data:** dU=CvdT (implied)
> **Warrant:** We just substitute this one into dU and then rearrange this equation right here (Mark).
>
> **Classroom B**
> **Claim:** dS = Cv/T dT + R/V dV
> **Data:** dU = CvdT = TdS - PdV
> **Warrant:** so substitute in Cvdt for U. add PV down here to that side. And divide by T. Flip it around, Well, we want volume and temperature, so I need to get rid of Pressure. Replace pressure with its definition. nRT divided by v. So I've got nRT over v times 1 over TdV, T's cancel out. Actually, we did molar volume, we don't need the n.

Both of these arguments follow a linear causal mathematical pattern described in Chapter 4 in which the claim is the final mathematical output, the data is the starting equation(s), and the warrant provides how the data leads to the final outcome. Arguments resulting from prompts that target the practice of using mathematics are largely descriptive of the computations. They are less revealing of students' understanding of the mathematical operations they are doing. When prompts explicitly target the practice of constructing explanations, students' arguments are more revealing of their understanding of the mathematics and chemistry content being targeted. For example, the following prompt explicitly elicits an explanation from students.

Consider a constant pressure process in which ΔrCp is greater than zero and does not depend on temperature. If temperature is raised, does the value of ΔrS increase, decrease, stay the same, or is it impossible to determine? Explain your reasoning.

Students generated the following arguments in response to this prompt.

Classroom A
Claim: It is impossible to determine what will happen to the value of ΔrS when you raise the temperature. (Melody)
Data: ΔrS T2 - ΔrS T1 = ΔrCp ln T2/T1 (book)
Warrant: It depends on whether the natural log of T2/T1 is greater or less than 1. (Melody)
Backing: Or even if it's not such a tiny amount, if it's much bigger, because like the natural log of 1.5 is less than 1. (Melody)

Classroom B
Claim: The change in entropy of the reaction gets bigger. (Quentin)
Data: Constant pressure process in which ΔrCp is greater than zero, and doesn't depend on temperature. The temperature increases. (POGIL Materials)
Warrant: You're increasing your final, then you're going to receive a bigger number (inaud) (math of logs). (Quentin)

Quentin and Melody reach different conclusions, but both use data provided in the curricular materials. In order to explain their reasoning about how the change in entropy of reaction will change throughout the process, Quentin and Melody have to discuss their understanding of changing variables and the underlying mathematics. Melody concludes that it is impossible to determine and uses the mathematical reasoning to justify her claim. Her warrant and backing are indicative of some misunderstandings of the phenomenon and the impact on the mathematics. Her warrant that "it depends on whether the natural log of T2/T1 is greater or less than 1" fails to incorporate the condition of increasing temperature, as that would mean that there is no way for the ratio of final temperature to initial temperature to be less than 1. However, she expresses a meaningful concern when she considers the magnitude of change, which is largely affected by logarithmic math. But this does not justify her claim that it is ultimately impossible to determine. Quentin uses simpler reasoning when he warrants that "you're increasing your final, then you're going to receive a bigger number", referring to increasing final temperature leading to a larger change in entropy. As a result of explicitly prompting for

explanation, students' arguments are more revealing of their understanding and reasoning. Additionally, data from Table 5.4, suggests that these prompts elicit more arguments than prompts targeting only the use of mathematics and computational thinking.

Effect of Cognitive Demand on Complexity of Causal Reasoning

Though there was not as noteworthy of a difference in the effect of cognitive demand and content-practices integration on the number of arguments, there was a noteworthy effect on the quality of resulting arguments.

Table 5.7. The percent of arguments using each mode of reasoning resulting from different TAGS labels (values given are in percentages).

TAGS	Descriptive	Relational	Linear Causal	Multicomponent
Memorized content (MC)	2	3	1	0
Scripted content (SC)	41	14	3	7
Scripted integration (SI)	44	64	70	7
Guided content (GC)	5	4	5	43
Guided integration (GI)	7	15	20	43

Table 5.7 indicates that the majority of descriptive, relational, and linear causal arguments result from Scripted integration (SI) prompts, while the majority of multicomponent arguments result from guided prompts (both GC and GI). These differences point to the necessity of prompts with high cognitive demand in order to elicit

more complex causal reasoning. Further, scripted prompts potentially limit students' opportunities to access more complex causal reasoning and incorporate that into their arguments. An exploration of the types of prompts from each TAGS category and the resulting arguments provides evidence of this effect.

Memorized content (MC) prompts elicit primarily relational and descriptive reasoning, but were less frequently represented in the POGIL curriculum. The following prompt and resulting argument provide an example from classroom A.

Focus Question: A hot brick is placed into cold water in an isolated container. The final temperatures of the brick and water are identical. What is the total energy change in this process:

a) Positive
b) Negative
c) Zero
d) Cannot determine without further information

This prompt was coded as memorized content as it targets the concept of energy conservation, which students in an upper-level chemistry class have previously encountered. In order to respond to this problem, students must know the first law or use experience, there is no process that they might undergo to answer the problem. The following resulting argument illustrates how students arrived at the answer.

> **Classroom A**
> **Claim:** The total energy change in the process is zero. (Garrett)
> **Data:** A hot brick is placed into cold water in an isolated container. The final temperatures of the brick and water are identical. (POGIL Materials)

Garrett utilizes relational reasoning when he claims that because the final temperatures of the brick and water are identical, "the total energy change in the process is zero." There is no explanation of what gives rise to the total energy change of zero. This argument suggests that Garrett did not think he needed to verbalize a justification for his claim,

which could indicate that the concept of energy conservation is assumed or well understood. The memorized content (MC) question did not elicit a very sophisticated argument.

As Table 5.6 shows, scripted prompts resulted in more variation in type of reasoning employed in arguments generated. Scripted content (SC) questions gave rise to a large percentage of the descriptive reasoning that occurred. The following SC example does not target a specific practice, but specifically tells students the considerations about content they are to make in order to answer it, earning a code of scripted for cognitive demand level.

$Mg(s) + CO(g) + O_2(g) \text{—>} MgCO_3(s)$
$MgO(s) + CO_2(g) \text{—>} MgCO_3(s)$
$Mg(s) + C(s) + 3/2\ O_2(g) \text{—>} MgCO_3(s)$
$BaCO_3(s) \text{—>} BaO(s) + CO_2(g)$
$CO(g) + 1/2\ O_2(g) \text{—>} CO_2(g)$
$C(s) + O_2(g) \text{—>} CO_2(g)$
In which of the above reactions is the product the result of the reaction of the elements that compose it, each of the elements being in their stable states at 1 bar?

The arguments that resulted were very descriptive, generating very little new information.

> **Classroom A**
> **Claim:** In reaction F, the product is the result of the reaction of the elements that compose it (Mark)
> **Data:** Model 4 chemical reactions (book)
>
> **Claim:** Reaction C fits that criteria as well (Garrett)
> **Data:** Model 4 chemical reactions (book)
>
> **Consensus claim:** Just C and F that are only composed of elements (Garrett)
> **Data:** Model 4 chemical reactions (book)
> **Warrant:** So you have to use the elements that compose it. So like A isn't because CO is a compound, B isn't because you have CO2 which is a compound, D isn't because BCO3 is a compound, E isn't because CO is a compound and so it's just C and F that are only composed of elements. (Garrett)

The arguments generated in classroom A are all correct and provide sufficient answers to the question. The nature of the prompt (SC) served to only require lower-level reasoning to answer sufficiently. Arguments from classroom B show similar patterns.

Classroom B
Claim: C and F are a result of the reaction of the elements that compose it. (Jerome/Jamal/Book)
Data: Model 4 chemical reactions (book)
Warrant: All the other reactions have molecules (Jerome/Jamal)

Claim: All the reactions are enthalpy of formation reactions except d (Jerome/Book)
Data: Equations (Book)
Warrant: D is a decomposition reaction (Jamal)

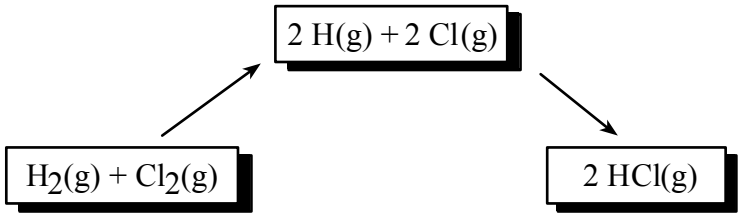
Claim: I think it's c and f, the same as in 12. (Jerome)
Data: Equations in book
Warrant: Yeah, cause those are the only ones that involve only stable state elements in the formation (Jamal)
Backing: Definition of enthalpy of formation produces 1 mole of product from the elements. (Jerome)

In two of the three arguments generated by Jerome and Jamal, the claim is that reactions C and F meet the requirements listed in the problem for a reaction to be an enthalpy of formation reaction. Jerome make a claim that "all the reactions are enthalpy of formation reactions except d" and Jamal justifies it with the warrant that "D is a decomposition reaction." Jamal is correct in considering reaction D as a decomposition reaction, which disqualifies it from being an enthalpy of formation reaction. However, this does not justify the claim that all the other reactions are enthalpy of formation reactions. This is rebutted within their discourse, giving rise to this last argument, which serves a consensus argument. These arguments, excluding the incorrect claim in the second argument from classroom B, are sufficient in answering the prompt, but they do not

expose very complex reasoning about the nature of the chemical reactions. Rather, all of the arguments reflect an approach that seems to check conditions off of a checklist. The prompt elicits this type of approach, limiting access to more complex reasoning that could be used to think about enthalpies of formation.

Scripted integration (SI) questions gave rise to a majority of the descriptive, relational, and linear causal reasoning. This is likely due to the frequent occurrence of scripted integration questions. Many of the SI prompts that gave rise to relational reasoning integrated the content with the practice of 'constructing explanations', while many of the SI prompts that gave rise to linear causal reasoning integrated the content with the practice of 'using mathematics and computational thinking.' The following SI prompt targets the practices of 'constructing explanations' and 'developing and using models' and elicits relational arguments from both classrooms.

Model 2:
H2(g) + Cl2(g) → 2HCl(g)



In terms of the value of the ΔrH for this reaction, does it matter whether the chemical transformation of H2 and Cl2 actually proceeds by the steps given in model 2? Why or why not?

The following arguments from classroom A and B demonstrate the relational reasoning used to answer this prompt.

Classroom A
Claim: The reaction doesn't proceed as steps shown in Model 2. (Mark)
Data: H is a state function/Model 2 page 64 (Mark/POGIL Materials)
Rebuttal: It does proceed as steps. (Jacob)
Warrant: The steps don't matter, because it is a state function. (Stephanie)

Classroom B
Claim: ΔH for a reaction does not depend on mechanism. (Caprice)
Data: It is a state function. (Caprice)
Warrant: It only depends on itself (final and initial). (Caprice/Instructor B)

Mark and Stephanie, in classroom A, argue that the reaction does not proceed by the steps shown because enthalpy is a state function. This is slightly different than the argument generated in classroom B in which Caprice and Instructor B argue that the change in enthalpy of reaction does not depend on the mechanism because it is a state function. Though classroom B's argument points to a more nuanced understanding of enthalpy of reaction, both arguments use the relationship between enthalpy as a state function and the steps proposed in Model 2 in order to justify their claims. The relationship is sufficient for the students in both classrooms to justify their answer to the prompt.

Scripted integration (SI) tasks targeting the practice of 'using mathematics and computational thinking' frequently elicit linear causal arguments. These linear causal arguments, as descripted in Chapter 4, assume the structure of mathematical descriptions in which the claim represents the final mathematical output, the data are the starting equation(s), and the warrant explains how to move from the data to the claim. The following prompt specifically targets the practice of 'using mathematics and computational thinking.'

Consider the Gibbs energy, G.

a) Based on its definition (G=A+PV), how do we know that G is a state function?
b) Show that G=U-TS+PV and provide an expression for *d*G.
c) Show that G=H-TS and provide an expression for *d*G.
d) Find ΔG for a constant temperature process in terms of H and S.

This prompt received a scripted code as it provides students with specific steps that are to be followed. The resulting argument sequences from both groups include linear causal and relational arguments targeting different parts of the prompt.

Classroom A
Claim: G is a state function. (POGIL Materials)
Data: Because A and PV are state functions. (Mark)

Claim: $\Delta H - T\Delta S = \Delta G$
Data: $H = U + PV$, $\Delta G = w$ (Stephanie)
Warrant: Substitute U in here, and then move these over to the side, and then take the integral. (Stephanie)

Classroom B
Claim: $G = U - TS + PV$ (Thaddeus/POGIL Materials)
Data: $G = A + PV$, $A = U - TS$ (solutions to previous problems)
Warrant: Substitute $A = U - TS$ for A in $G = A + PV$ (Thaddeus)
Claim: $G = H - TS$ (Francis/POGIL Materials)
Data: $H = U + PV$ (Francis/board)
Warrant: pull out a U and $A + PV$, end up with $G = H(-TS)$.

Claim: $\Delta G = \Delta H - T\Delta S$ (Class)
Data: $dG = dH - TdS - SdT$ (Quentin/board)
Warrant: At constant temperature, last term cancels out. The rest of the terms are state functions, so can be considered as deltas. (Instructor B/Class)
Rebuttal Claim: So wouldn't $\Delta G = 0$?(Caprice)
Rebuttal Data: $\Delta H = T\Delta S$ (Caprice)
Rebuttal: Is that true? (Instructor B)
Resolution: $\Delta G = 0$ for reversible process at equilibrium. (Instructor B/Caprice)
Data: $\Delta H = T\Delta S$ (Caprice)
Warrant: Data is only true for a reversible process at equilibrium. (Caprice/Male/Instructor B)

In classroom A, Mark makes an argument that G is a state function because A and PV are state functions. This reasoning is characteristic of relational reasoning described in Chapter 4. Stephanie's argument in classroom A and arguments in classroom B by Thaddeus, Francis, Quentin, and Instructor B follow the linear causal mathematical pattern explained above. In all of these arguments, the claim is the output suggested in

the prompt and the warrant provides the route taken to get to the output. The rebuttal argument and resolution argument follow a slightly different pattern as it is targeting an alternative conception held by Caprice rather than aiming to answer the question. The structure of the question, which scripts the output a student should generate and the starting equations that should be used, shapes the resulting arguments to assume this linear causal mathematical form.

There were scripted integration (SI) questions that elicited a range of argument types in response. The following example illustrates an SI prompt that targets the practice of 'using mathematics and computational thinking' and elicits relational arguments from the students, but a linear causal argument from the instructor.

Calculate ΔU for an isothermal process for an ideal gas in which the pressure increases from 1 bar to 10 bar.

This prompt explicitly elicits a calculation, which requires use of an equation previously provided in the activity, earning it a scripted integration code. The following arguments from both classrooms illustrate the students' reasoning used to justify their answer to the prompt.

Classroom A
Claim: Δ U = 0 (Qi)
Data: It is isothermal. (Melody/book)
Warrant: Because isothermal means Δ T is zero. (Melody)
Claim: Δ U = 0 (Qi)
Data: Isothermal, Δ T = 0 (Melody)
Warrant: *For an ideal gas, the energy is only dependent on temperature.* (Melody)
Backing: *They really want us to know that energy is only a function of temperature.* (Melody)
Claim: The energy of an ideal gas is a function of the temperature only. (Instructor A)
Data: Temperature is a direct measure of how fast the of the average kinetic energy. (Instructor A)

Data: Ideal gas does not have forces between particles. (Melody)
Warrant: But if there are no forces between the particles, which is what an ideal gas is, we assume there are no forces between the particles, that means there is no potential energy, so every energy change is a kinetic energy change, so it all goes back to the fundamental idea of what an ideal gas is. (Instructor A)
Backing: Some thermal energy can go into vibrational and rotational modes, but most goes into translational modes (Instructor A)

Classroom B
Claim: $\Delta U = 0$ for an isothermal process for an ideal gas in which the pressure increases from 1 bar to 10 bar. (boards)
Data: isothermal process (Male)
Warrant: delta T = 0, therefore delta U = 0 (Instructor B)

Excluding Dr. Green's argument in classroom A, the arguments draw from the relationship between internal energy and temperature for an ideal gas. This type of reasoning is targeted by the prompt, evidenced by the prompts leading up to this one in which students constructed the concept of temperature dependence of internal energy. This is confirmed by Melody's backing in which she says "They really want us to know that energy is only a function of temperature." Dr. Green provides a more complex linear causal argument in which he incorporates the definition of an ideal gas as having no forces between particles. This argument is sophisticated and explicit, representing the type of reasoning that would ultimately be desired of students; however, the prompt does not serve to elicit this type of reasoning.

Table 5.7 shows that the majority of multicomponent reasoning is elicited by guided tasks. Guided prompts require students to generate new information that is not provided to them. They often involve synthesizing prior knowledge, resulting in more complex reasoning. In the following example, a guided content (GC) prompt elicits multicomponent reasoning in which students explicitly consider multiple variables.

> Suppose a given chemical mixture has the potential to produce products so that the sum of the bond strengths is larger than those of the reactants but that the number of moles of reactant gases are decreased. Will the reaction occur?

This prompt requires students to make a prediction in which they synthesize their prior knowledge. This task is situated at the beginning of an activity which introduces Gibbs energy and Helmholtz energy as concepts for determining the direction of chemical processes. Further, students must consider and weigh at least two variables (enthalpy change and entropy change) to answer the prompt. The arguments generated in classroom B illustrate how students considered and weighed these two variables.

Classroom B

Claim: Reaction will not go. (Liam)
Data: More moles of reactant, less moles of product (entropy decreases). (Liam)
Warrant: Spontaneity determined by entropy to determine direction (reaction won't go towards a lower entropy). (Liam)
Claim: Reaction does occur. (Brian)
Data: Sum of products bond strengths is larger than reactants, number of moles reactant decreases. (POGIL Materials)
Warrant: *So the combustion of hydrogen forms water so you have 1.5 moles to every mole of product and we know that ΔH for that is negative release of energy and we know that reaction does occurs so we know that's ΔS is positive.* (Brian)

Claim: Maybe the reaction will occur. (Jerome)
Data: Sum of products bond strengths is larger than reactants, number of moles reactant decreases. (POGIL Materials)
Warrant: *We argued if your bond strength gains, or if your change, if it's energetically favorable enough, your product, your bond strength gains, then it will outweigh any uh, entropy losses so it could still happen.* (Jerome)

Claim: The reaction will not occur. (2 groups)
Data: Sum of products bond strengths is larger than reactants, number of moles reactant decreases. (POGIL Materials)
Data: Entropy of the system is negative (2 groups). (entropy won't increase because there are fewer moles and greater bond strength)
Warrant: Reaction will not occur is entropy of the system is negative. (Instructor B/Caprice)

Rebuttal Claim: Only entropy of the universe determines spontaneity (Instructor B/Kayden)
Qualifier: Gibbs energy is necessary to consider the perspective of the system (Instructor B)
Rebuttal Data: $\Delta H < 0$, $\Delta S < 0$ (Instructor B)
Rebuttal Warrant: One favors reaction, the other disfavors. (Instructor B/Kayden)
Rebuttal Backing: Must consider magnitudes. There is not enough information to determine if the reaction will go or not (Instructor B)

Liam claims that the reaction will not proceed due to a decrease in entropy and draws on his knowledge that spontaneity is determined by entropy, which ultimately determines direction. Brian incorporates a chemical reaction that he is familiar with and also applies to the hypothetical reaction in the question in order to justify that the reaction proceeds forward. Jerome claims that "maybe the reaction will occur." His reasoning is that it is possible for the bond strength gains to outweigh entropy losses. In all three of these arguments, students are considering and weighing the change in entropy and enthalpy. In order to do this, they incorporated prior knowledge in the form of additional variables, such as spontaneity or an example chemical reaction. In Jerome's case, weighing both variables resulted in a less conclusive claim that the reaction was possible. The last argument serves to synthesize multiple small groups' answer to this question, after which Instructor B introduces the concept of Gibbs energy as direction determining. This GC prompt provided students the opportunity to use more complex causal reasoning to answer.

Guided integration (GI) prompts also elicited a large percentage of multicomponent reasoning. The following prompt required students to plan an investigation that would allow them to determine heat capacity for a constant volume process.

Describe a process that could be used to determine $\bar{C}$v.

This prompt provides no specific steps the students must follow to reach an output and specifically targets the practice of 'planning and carrying out an investigation.' The argument sequence generated in response to this prompt was provided before as an illustration of the positive discursive move of rebuttals serving to further discourse, but it is also illustrative of complex causal reasoning.

Classroom B
Claim: A bomb calorimeter could be used to determine Cv. (Reed)
Data: By using a standard, then you know U.
Data: Bomb is constant volume (Reed)
Data: Cv equals [writes (du/dt)] (Reed/Instructor B)
Warrant: so you can solve for the change for U, or the, you can solve for the U over dT, so you can solve for the change in energy with respect to temperature … {additional discussion} Because you're going to make the temperature change. And you know what your change in energy is, because you know how much energy you put in, and assuming you know how much it used, then you know much is used. (Reed)
Warrant: We use the bomb because that gives me the process at constant volume. (Instructor B)
Request for clarification: How would you know how much energy you used? (Callum)
Clarification: Use standard mass to know how much internal energy there is. (Reed)
Rebuttal: you're not really accounting for base changes or difficult reaction processes. (Quentin)
Rebuttal Data: you're burning a substance so you're going to have combustion, you're going to be breaking down bonds and everything. (Quentin)
Rebuttal Warrant: So you're not really accounting for the molar heat capacity, isn't that just increasing the temperature of a substance by a certain amount? (Quentin)
Counter Claim: Apply a certain amount of energy to a substance and measure the temperature change [to determine heat capacity]. (Quentin)
Data/Warrant: You need to know how much of the substance you have (Quentin)
Data/Warrant: Assuming density doesn't change. He said the volume has to be constant. (Callum)

In the initial argument, Reed claims that a bomb calorimeter could be used to determine Cv. He considers multiple variables and how he intends on manipulating those variables to measure a value for molar heat capacity for a constant volume process. Callum seeks elaboration on how Reed can measure internal energy. Quentin introduces consideration of "base changes" and "difficult reaction processes", for which he provides combustion as an example. Finally, Callum incorporates the concept of constant density so as to have constant volume. Quentin and Callum contributed new variables for consideration by the whole group. The guided level of cognitive demand and targeted practice of 'planning and carrying out an investigation' in this question facilitated the use of complex causal reasoning and consideration of multiple variables.

Summary of Findings

The practices being targeted by POGIL prompts had a larger effect on the number of arguments generated than the level of cognitive demand, while the cognitive demand had a larger impact on the quality of causal reasoning present in resulting arguments. The practice of 'constructing explanations' and 'engaging in argument from evidence' showed to result in the most arguments per prompt. This means that explicitly requiring students to explain or defend their reasoning results in more argumentation.

Of the cognitive demand levels, Scripted prompts elicited a majority of the relational and linear causal reasoning with Scripted integration tasks targeting the practice of 'constructing explanations' eliciting many of the relational arguments and those targeting 'using mathematics and computational thinking' eliciting many of the linear causal arguments. Further, guided prompts elicited the majority of multicomponent

arguments. Though these trends suggest that the cognitive demand and targeted practice of the question has an effect on the nature of the resulting argument, these features are not the only determinant of the reasoning that students use in their arguments. That is, there were guided prompts that elicited lower level reasoning and memorized content prompts that elicited higher level reasoning. However, these results do suggest that cognitive demand and targeted practice served to provide opportunities for students to access different levels of reasoning complexity.

The TAGS framework was especially appropriate for explaining the effect of the POGIL curriculum on the differences in argumentation that were observed across two classrooms. Specifically, it was useful for incorporating scientific practices into evaluation of argumentation to justify targeting a variety of scientific practices in order to elicit argumentation. Additionally, this framework allowed for consideration of cognitive demand of the POGIL tasks to explain the complexity of the resulting arguments.

CHAPTER 6. CONCLUSIONS AND IMPLICATIONS

Discursive Differences and Instructor Influence

Results and analysis highlighted differences between discursive moves in the two classrooms. Classroom B's discursive moves were reflective of more sophisticated argumentation. Students in classroom B were able to generate clear, explicit warrants that served to connect the data to the claim; construct rebuttals that targeted specific weaknesses in each other's arguments; and rebut each other's arguments so as to propagate more discourse. In contrast, there were instances in classroom A in which warrants were unclear or failed to connect the data to the claim. Further, rebuttals served to input the correct answer and halt conversation, rather than showing evidence of careful consideration of another person's argument.

The theoretical underpinnings of this work, the sociocultural perspective and situated learning, provide context for interpreting the differences in discursive moves that were observed. According to both frameworks, the discursive moves present in classroom B provide evidence of learning. According to Mercer (2007), the quality of classroom discourse is related to the quality of learning, because students undergo a process of internalization of socially constructed meaning in the classroom. The difference between classroom A and B in discourse affects what can be internalized by the students. Students

in classroom B, then, were able to internalize socially constructed knowledge that was more reflective of the nature of scientific inquiry and discourse.

Further, students' level of participation in scientific discourse is revealing of the level of enculturation into the scientific community. The discursive moves present in classroom B are more reflective of the nature of scientific discourse, which means that students in that classroom are more authentically participating in the scientific community. As students have more access to the discursive tools used by the scientific community, they are better equipped to learn the content knowledge constructed by that community. Facilitating students' engagement in argumentation is one way to help students engage in legitimate peripheral practice, which has implications for students' learning of content.

Differences in argumentation between the two classes were largely explained by differences in instructor facilitation. Particularly, Instructor B's explicit and implicit instruction regarding argumentation and classroom structure resulted in more arguments that were more sophisticated and used more complex causal reasoning. Christodoulou and Osborne (2014) highlight the role of the instructor in facilitating argumentation by both explicitly targeting the practice and modeling the practice of argumentation. Instructor B engaged in both of these discursive moves (targeting and modeling) more explicitly than Instructor A.

Instructor B targeted argumentation with explicit instruction regarding how to engage in argumentation in two ways. Firstly, Instructor B introduced the Toulmin model of argumentation as an expected means of engaging in discourse in the classroom. Secondly, Instructor B rebutted students' arguments with explicit feedback about how to

engage in arguments. For example, she responded to an argument in class with the statement, “You make a claim, then explain it, why is that last term essentially going to be zero?” This question served to both elicit justification and communicate an expectation for justifications. Instructor B also modeled argumentation by providing argument components (I.e. warrants, rebuttals, qualifiers). This instructor discursive move serves to further emphasize the expectation for students to construct arguments as well as provide examples of how to construct arguments.

Argumentation and Causal Reasoning

Students in both classrooms used primarily relational reasoning, which makes use of a relationship to justify a claim or outcome without explaining the relationship. This tendency towards use of relational reasoning is likely due to multiple factors including facilitation, curriculum, and social and cultural norms within each classroom. According to Berland and Reiser (2009), facilitating argumentation is one way to promote causal reasoning as students must often consider causal mechanisms in order to justify an outcome or claim well. The increased amounts of linear causal and multicomponent reasoning in classroom B indicate support Berland and Reiser’s (2009) claim. Effectively facilitating argumentation in the classroom has the potential to implicitly promote more complex causal reasoning by placing an expectation on students to verbalize sufficient justifications for claims.

POGIL and Argumentation

The curriculum had an effect on the number and type of arguments generated in the classroom. The scientific practice targeted by the POGIL prompt had an appreciable influence on the number of resulting arguments. Questions that targeted the practice of 'constructing explanations' and 'engaging in argument from evidence' resulted in the highest number of arguments per prompt. Requiring students to answer questions with justifications results in more arguments.

The cognitive demand and integration of scientific content and practice impacted the nature of resulting arguments. That is, prompts with a higher cognitive demand were able to elicit arguments with more complex causal reasoning, while prompts with lower cognitive demand required less complex causal reasoning to answer. Different levels of causal reasoning are appropriate for solving different types of problems. However, it is important to provide students opportunities to access and develop complex causal reasoning so that they are able to use it readily when needed, as experts are able to do (Sevian & Talanquer, 2014).

Implications for Practice

The results from this study have implications for instructors aiming to facilitate argumentation, implementation of the POGIL approach, and the organization and structure of the POGIL curriculum itself. To effectively facilitate argumentation, it is important to explicitly put forth the expectation for students to construct arguments and provide an argument model for students (Quintana et al., 2004). Toulmin's (1958) model of argumentation has been widely used to provide students explicit criteria for how to

construct an argument (Osborne et al., 2004; McNeil et al., 2006; Berland & Reiser et al., 2011). Further, this expectation for students to construct arguments must be continually communicated throughout the course. Instructor B reminded students by giving explicit feedback to students on how to communicate explanations in real time.

The results from this work build on studies arguing that establishing a goal of consensus-building is key to effective engagement in argumentation (Garcia-Mila, Gilabert, Erduran, & Felton, 2013; Clark & Sampson, 2008; Sampson & Clark, 2009). Instructor B implicitly established this goal by engaging students in whole class discussion in which each small group presented their solutions to the whole class and the whole class discussed until consensus was reached. Explicitly establishing this goal by communicating it to students is also effective.

Finally, instructors can prompt students for justifications. Instructor B did this by responding to students with "why" or "I don't understand." This discursive move has been shown to support the construction of arguments by eliciting warrants from students (Christodoulou & Osborne, 2014). Instructors can model argumentation for students by contributing to arguments. This provides students with examples of argument components and serves to communicate epistemic criteria for argument quality. Ultimately, effective facilitation of argumentation as a mode of discourse within the classroom requires ongoing intentional support by the instructor.

This work has resulted in recommendations for implementation of the POGIL approach and changes to the organization and structure of the POGIL Thermodynamics curriculum. The curriculum alone is not sufficient for supporting authentic engagement in scientific inquiry or discourse. This was evidenced in classroom A by the value placed on

getting the correct answer at the expense of engaging in effective discourse. In addition to the recommendations for instructor facilitation reported above, instructors can emphasize focus questions, which are used to introduce new concepts each POGIL activity. These questions require students to use their prior knowledge to consider a concept they may not be familiar with. Placing an emphasis on questions that have high cognitive demand and an exploratory purpose can result in a classroom shift towards more authentic scientific inquiry.

To make the curricular prompts more effective at supporting argumentation, more prompts must explicitly elicit explanation. One way to do this is to add "Why?" or "Explain your reasoning" to existing prompts. This curriculum currently overemphasizes the practice of 'using mathematics and computational thinking', which is less conducive to scientific discourse than practices of 'constructing explanations', 'developing and using models', 'engaging in argument from evidence', and 'analyzing and interpreting data.' POGIL prompts that target a more diverse set of scientific practices can better support scientific discourse.

Finally, there must be more prompts with higher cognitive demand within each activity. Results from this study showed that prompts with higher cognitive demand were able to elicit more complex causal reasoning. It is essential then to provide students with opportunities to access and develop more complex causal reasoning, so that they can use it to understand and solve more complex problems in thermodynamics. There is room within the application phase of the POGIL activity cycle to incorporate questions with high cognitive demand.

Implications for Research

Very little research has been done which investigates students or classrooms in upper-level undergraduate STEM courses (Bain et al., 2014; NRC, 2012; Becker et al., 2013, 2015). The results from this study contribute to this body of work by providing a greater understanding of the nature of physical chemistry students' engagement in the practice of scientific argumentation (Cooper et al., 2015) and evaluating the POGIL thermodynamics curriculum (NRC, 2012). However, more work is needed in the context of physical chemistry. This could involve investigation of physical chemistry students' understanding of specific topics (e.g. thermodynamics, quantum mechanical models, kinetics) or engagement in scientific practices (e.g. modeling, argumentation, using mathematics).

Research into student engagement in scientific practices across the undergraduate chemistry curriculum is scarce. Because of this, it is difficult to characterize what is expected of students as they engage in these practices. For example, it is not well understood how arguments generated by physical chemistry students might differ from arguments generated by students in lower level chemistry courses. Research, then, could investigate students' engagement in these practices across the curriculum in order to develop learning progressions for each practice.

Learning progressions for each practice could then be used to inform curricular changes that might promote vertical alignment within the undergraduate chemistry program. This type of vertical alignment could provide opportunities for chemistry majors to engage more authentically in the field of chemistry and thus be better prepared for participating in this field upon graduation.

Finally, the relationship between students' engagement in scientific practices and development of scientific knowledge is not well understood. Further investigation of how students' engagement in scientific argumentation impacts their understanding of physical chemistry is needed. To study this relationship, there must be simultaneous assessment of content knowledge along with attention to scientific argumentation, whether this be in the form of an intervention or ongoing classroom discourse. A comparison of students' content knowledge in a classroom engaging in argumentation and a traditional physical chemistry classroom would also support an understanding of the relationship between argument and content.

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APPENDICES

Appendix A: Classroom A Argument Logs

Small Group Work Argumentation Log for 10/17/2013

[0:48 - 2:09]
SGW 10/17/2013 ChemActivity T1: Work, CTQ 5a
Claim: The volume is A times l initial. (Jacob)
Data: Model , page 42. (POGIL Materials)
Warrant: *So you have to think about this as like 3 dimensional object right like the top of the thing down to the bottom thing have the same height and that's just your area and the length can just be how far apart they are. So your volume at the beginning of it would be ... your length initial times the area of that thingy.* (Jacob)

[5:41 - 5:50]
SGW 10/17/2013 ChemActivity T1: Work, CTQ 4
Claim: $P_{ex}dV$ (Stephanie)
Data: P_{ex} = f/A, dw = f*-dl (POGIL Materials, CTQ3)
Warrant: *So A is equal to dV over dl and then plug that into the P_{ex} equation, and solve for F. So have F = P_{ex} * dq/dl I put that right here and then this time dl and solve for dl.* (Stephanie)

[24:58]
SGW 10/17/2013 ChemActivity T1: Work, CTQ 6
Claim: There is no work. (Jacob)
Data: *Because if there is zero pressure there is no force.* (Jacob)

[40:49 - 41:33]
SGW 10/17/2013 ChemActivity T1: Work, CTQ 11b
Claim: Yes the process is against constant external pressure (Mark)
Data: Model 3, page 45. (POGIL Materials)

[42:40 - 43:21]
SGW 10/17/2013 ChemActivity T1: Work, CTQ 12
Claim: To be reversible, pour infinitely tiny sand grains onto it. (Garrett)
Data: Because the internal and external have to be equal. (Stephanie)
Warrant: *I suppose you can vary pressure continuously. I mean that's really what I'm getting at by pouring the very tiny sand grains onto it.* (Garrett)
Backing: *Without changing the ratio of the pressures or the sum of the pressures the other way.* (Garrett)
Rebuttal: It has to be realistic. (Stephanie)

[45:09]

SGW 10/17/2013 ChemActivity T1: Work, CTQ 11d
Claim: Yes there is an equilibrium state. (Mark)
Data: *Because once you remove one, the other extends, and there is an imbalance in pressure and they eventually will even out.* (Mark)

[53:22 - 54:09]
SGW 10/17/2013 ChemActivity T1: Work, CTQ 13
Claim: dw = -nRT/V dV (Stephanie)
Data: Ideal Gas Law PV=nRT, P = dw/dV (Stephanie/Jacob)
Warrant: Substitute P for the ideal gas law. (Stephanie)

[53:22 - 54:09]
SGW 10/17/2013 ChemActivity T1: Work, CTQ 13
Claim: dw = -nRT/V times dV (Stephanie)
Data: dw = $-P_{ext}dV$ (CTQ 4, Stephanie)
Data: Ideal Gas Law PV=nRT (POGIL Materials)
Warrant: Solve for P external you get P external = -dw/dV, then you can substitute that into the PV=nRT so you have -dw/dV times V = nRT. (Stephanie)

[58:26 – 58:43]
SGW 10/17/2013 ChemActivity T1: Work, CTQ 15
Claim: For non-isothermal process, integral would be much harder. (Stephanie)
Data: T is in the integral (Stephanie)
Warrant: *So isothermal .means the temperature is not changing* (Stephanie). If temperature was changing, *I think in terms of two variables, who wants to do that, that's not good.* (Jacob)

[01:01]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, FQ
Claim: The total energy change in the process is zero. (Garrett)
Data: A hot brick is plaed into cold water in a isolated container. The final temperatures of te brick and water are idenitical. (POGIL Materials)

[5:27 - 6:53]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 4a
Claim: Yes work is being done. (Stephanie)
Data: Model 1, page 52. (POGIL Materials)
Warrant: Increasing the volume and the temperature (Stephanie)

[6:48 – 7:16]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 4a
Claim: Work sign is positive. (Mark)
Data: Model 1, page 52. (POGIL Materials)
Warrant: Work is being done by the system. (Mark)

Rebuttal Claim: Work is being done on the system. (Jacob)
Rebuttal Data: Model 1, page 52. (POGIL Materials)
Rebuttal Warrant: *The system hasn't done anything, if you think about it the system is using energy as ... and spitting it outside, to do it on the system is kind ... inside.* (Jacob)

[07:08 - 07:16]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 4b
Claim: The magnitude of work increases. (Stephanie)
Data: Model 1, page 52, - heating the system. (POGIL Materials)

[8:33 – 10:33]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 4b
Claim: The magnitude of work would increase. (Jacob/Stephanie)
Data: Model 1, page 52, - heating the system. (POGIL Materials)
Warrant: *Because more work is being done. Because the distance will change more.* (Jacob)
Rebuttal Claim: The magnitude of work would decrease. (Garrett)
Rebuttal Data: Model 1, page 52, - heating the system. (POGIL Materials)
Rebuttal Warrant: Gravity is negative. (Garrett)
Rebuttal: *I think gravity would be positive in this case*, *because it's weird just to have potential energy decrease.* (Mark)

[14:17 - 19:19]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 5c
Claim: $U_{wt} = PdV$ (Mark)
Data: dh = dl, F=mg, P=F/A (Group)
Data: mg/a is the external pressure (Garrett)
Data: h*A = V (Mark)
Warrant: *You just replace delta h times h with PV, You just take this thing and then pressure is equal to force over area, mass times gravity of equal to force, So you can uh if you multiply this by area then you can substitute pressure in* (Mark)

[19:56-20:53]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 6a
Claim: External pressure stays the same. (Mark/Garrett)
Data: Weight is not changing. (Garrett)
Warrant: The weight is going to be the source of the pressure. (Garrett)

[19:56-20:53]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 6b
Claim: *Internal pressure is not constant.* (Stephanie)
Data: *Volume is changing*. (Stephanie)
Warrant: *The pressure is still increasing.* (Stephanie)

[29:07 - 29:17]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 8
Claim: The signs are positive. (dUsys = dq + dw) (Garrett)
Data: Based on Model 2, page 55 (Jacob/POGIL Materials)
Data: Which means that heat is being transferred to the system. (Garrett)
Warrant: When the surroundings get colder q is defined as being positive. (Garrett)

[39:20]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 10c
Claim: Must change both pressures to achieve a reversible process (Dr. Green)
Data: Must be at equilibrium always (Dr. Green)
Warrant: It takes infinite time so it is difficult to achieve (Dr. Green)

[40:19 - 40:44]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 11b
Claim: dUsys = dq (Mark)
Data: dU = dq - dw (Mark)
Warrant: dw is zero because the volume is constant. (Mark)

[44:26 - 44:55]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 11a
Claim: dw at constant volume would just be a change in pressure. (Jacob)
Data: dw = -PdV (implied)
Rebuttal Claim: dw would be zero at constant volume. (Garrett)
Rebuttal Data: Because dV would be zero. (Mark)
Rebuttal Warrant: That's why dw cancels out. (Stephanie)

[45:26 - 45:50]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 15
Claim: For all processes change in total energy would be the same overall. (Group)
Data: Conservation of Energy. (Stephanie/Garrett/Jacob)

[48:27 - 50:07]
SGW 10/17/2013 ChemActivity T2: The First Law of Thermodynamics, CTQ 12
Claim: I said dq = dUsys - PdV (Stephanie)
Data: dUsys = dq - dw (Stephanie/Data from 11, Mark)
Warrant: *So it's that same in 10c, it's the same equation but we just solved for dq we had this equation but we said that dq is equal to zero, so it ended up just being this, but here we are using the whole equation and solving for dq.* (Stephanie)
Small Group Work Argumentation Log for 10/18/2013

[11:34 - 11:49]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 1a
Claim: PV would be a state function. (Mark)
Data: U is a state function. (Mark)

Warrant: *So PV is a state function because it's a measure of energy, which is a state function. (Garrett)*

[11:34 - 12:11]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 1b
Claim: PV a state function (Garrett/Mark)
Data: U is a state function (Mark)
Warrant: *Because it's a measure of energy, which is a state function* (Garrett)
Backing: *The pressure is what it is, it doesn't matter what path the system took to get there. And the same with the volume* (Dr. Green)

[13:41 - 13:52]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 1a
Claim: H is a state function (Mark/Stephanie)
Data: *PV is a state function* (Mark)
Warrant*: So U is a state function and H is a state function*. (Mark)

[14:58 - 15:07]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 3
Claim: dH = dU + PdV for a constant pressure process (Garrett)
Data: H = U + PV, dP=0. (POGIL Materials)
Warrant: Take the derivative and use the multiplication rule resulting in dH = dU + PdV + VdP, but last item goes to zero (Garrett/Stephanie/Mark)

[20:06 - 20:29]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 5b
Claim: dH = dq (Mark)
Data: dU = dq + dw, dH = dU+ PdV (Mark, POGIL Materials)
Warrant: *Constant pressure so there is no work if there is constant pressure*. (Mark)

[26:33 - 27:07]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 6
Claim: No the chemical transformation does not occur by the given steps. (Garrett)
Data: Model 2, H is a state function. (POGIL Materials, Garrett)
Warrant: *Because it's a state function and the path is not important.* (Stephanie)

[33:25 - 33:54]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 7
Claim: The reaction doesn't proceed as steps shown in Model 2. (Mark)
Data: H is a state function/Model 2 page 64 (Mark/POGIL Materials)
Rebuttal: It does proceed as steps. (Jacob)
Warrant: The steps don't matter, because it is a state function. (Stephanie)

[45:29 - 45:45]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 10

Claim: The ΔH of reaction is 44.01 KJ/mol. (implied)
Data: Heat of formation reactions and ΔH values, Model 3 page 66 (POGIL Materials)
Warrant: You add the reverse reaction, because you are going from H_2 liquid to H_2 gas, so you want to add the reverse. (Stephanie)

[48:17 - 19:14]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 12
Claim: In reaction F, the product is the results of the reaction of the elements that compose it. (Mark)
Data: Model 4 chemical reactions, page 67. (POGIL Materials)
Rebuttal Claim 1: Reaction C, fits that criteria as well. (Garrett)
Rebuttal Data 1: Model 4 chemical reactions, page 67. (POGIL Materials)
Rebuttal Claim 2: I'm not sure about Reaction C. (Mark)
Rebuttal Data 2: Model 4 chemical reactions, page 67, C has an O_2. (Mark)
Consensus Claim: Just C and F that are only composed of elements. (Garrett)
Data: Model 4 chemical reactions, page 67. (POGIL Materials)
Warrant: So you have to use the elements that compose it. So like A isn't because CO is a compound, B isn't because you have CO_2 which is a compound, D isn't because BCO_3 is a compound, E isn't because CO is a compound and so it's just C and F that are only composed of elements. (Garrett)

[49:42 - 50:46]
SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 13
Claim: All reactions are enthalpy of formation reactions except D. (Mark)
Data: Model 4 chemical reactions, page 67. (POGIL Materials)
Rebuttal Claim 1: No, all reactions are enthalpy of formation reactions except D and F. (Garrett)
Rebuttal Data 1: Model 4 chemical reactions, page 67. (POGIL Materials)
Rebuttal Warrant 1: Enthalpy of formation implies that you have the following conditions: one mole produced and the product is a result of the elements that compose it. (Garrett)
Rebuttal: Why Reaction D? (Stephanie)
Rebuttal Warrant 1: Because Reaction D is forming one mole of product and is composed of elements. (Garrett)
Rebuttal Claim 2: Reaction D is not an enthalpy of formation reaction. (Stephanie)
Rebuttal Data 2: Model 4 chemical reactions, page 67. (POGIL Materials)
Rebuttal Warrant 1: Reaction has 3 moles of products. (Jacob)
Consensus Claim: Reaction C is an enthalpy of formation reaction. (Garrett)
Consensus Data: Model 4 chemical reactions, page 67. (POGIL Materials)
Consensus Warrant: It meets both conditions for enthalpy of formation: one mole produced and the product is a result of the elements that compose it. (Stephanie)
Consensus Backing: So if Reaction C somehow resulted in $2MgCO_3$ then it wouldn't be an enthalpy of formation reaction. (Garrett)

[53:52 - 55:56]

SGW 10/18/2013 ChemActivity T3: Enthalpy, CTQ 15
Claim: The Δ H of reaction is 100 KJ/mol (Mark)
Data: Data: heat of formation reactions and values provided in the question (POGIL Materials)
Warrant: 1095.8 - 601 - 393 (Mark)
Rebuttal to Warrant: *The first and second reaction to be positive.* (Stephanie)
Rebuttal Claim: The ΔH of reaction is -100 KJ/mol. (Stephanie)
Rebuttal Data: Heat of formation reactions and values provided in the question. (POGIL Materials)
Rebuttal Warrant: *Because those are the ones, you want the reverse of those because you want to break those bonds, but for the last one you want to make those bonds, so breaking bonds is always a positive enthalpy, and making bonds is always a negative enthalpy.* (Stephanie)

Small Group Work Argumentation Log for 10/21/2013

[11:28 - 11:53]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 4a
Claim: ΔS_{total} has a positive sign. (Garrett)
Data: (S_{tot})final = (S_{tot})initial (POGIL Materials)
Rebuttal Claim: It is reversible. (Stephanie)
Rebuttal Data: ΔS final = ΔS initial (POGIL Materials)
Rebuttal Warrant: If the inequality applies the process is irreversible it will occur naturally. If the equality applies the process is reversible or at equilibrium. (Stephanie)

[15:24 - 16:41]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 4b & 4c
Claim: The forward and reverse processes would be spontaneous. (Garrett)
Data: (S_{tot})final = (S_{tot})initial (POGIL Materials)
Warrant: The process is reversible. (Garrett)
Rebuttal Claim: The forward process wasn't spontaneous. (Mark)
Rebuttal Data: (S_{tot})final = (S_{tot})initial (POGIL Materials)
Rebuttal Warrant: Because it says for an event to occur spontaneously ΔS total must be positive (Mark)
Rebuttal Backing: *You see the argument that you just told me for 3c... I was thinking because the ... and the reverse in this case.. It says it reversible but it doesn't say the reverse process because if you think in a reverse process it can... the initial is still going to equal the final change, once you get there.* (Stephanie)

[19:06 - 21:05]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 1
Claim: Spontaneous means that it just happens. (Jacob/Mark)
Data: Process occurs at standard conditions (Not ridiculously high or low temperatures or pressures). (Mark)

Rebuttal Claim: Spontaneous process occurs without exterior interference. (Garrett)
Rebuttal Data: *It's happening entirely within the system.* (Garrett)
Rebuttal Warrant: This means the process would not require external energy. (Garrett)
Rebuttal Qualifier: This can happen at any temperature. (Garrett)

[30:52 - 33:29]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 4a
Claim: $\Delta S_{total} = 0$ and has a positive sign. (Mark)
Data: (S_{tot})final = (S_{tot})initial (POGIL Materials)
Data: *For an event to occur spontaneously change in S total must be positive.* (Stephanie)
Warrant: I guess it's not negative, so it must be positive. (Jacob)

[42:23 - 43:19]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 4d
Claim: *The process at equilibrium is not spontaneous.* (Garrett)
Data: $\Delta S = 0$ (Dr. Green)
Warrant: *For an event to occur spontaneously ΔS universe must be positive, So that means that the equality doesn't hold for an event to occur. (*Dr. Green)
Backing: *So another way of thinking about that is what is occurring at equilibrium at the macroscopic scale, nothing.* (Dr. Green)

[46:24 - 46:58]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 6b and 6c
Claim: *The temperature of the water will increase and the temperature of the brick will decrease.* (Garrett)
Data: The First Law Thermodynamics. (Garrett)
Warrant: *The first law thermodynamics provides how the process would happen, like in terms of what the temperature will be doing relative to each other but doesn't explain why the process would happe*n. (Garrett)
Rebuttal: *But it says we're going to have to an adiabatic enclosure which means transfer of energy as heat is not allowed.* (Stephanie)
Response: B*etween the system and surroundings but between the elements of the system it doesn't say anything about, yeah.* (Garrett)

[50:09]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 6c
Claim: No question 6b is not based on the first law of thermo. (Garrett)
Data: *Because the first law thermodynamics provides how the process would happen and how the temperature should change relative to each other but it doesn't explain why they would equilibrium the first place.* (Garrett)

[52:32 - 52:51]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 6f
Claim: ΔS total for the process has a positive sign. (Garrett)
Data: Because it is spontaneous. (Garrett)

[53:28]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 6d
Claim: $\Delta U_{total} = 0$ (MArk)
Data: Because energy is conserved. (Mark)

[56:18]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 6f
Claim: Something at equilibrium can be reversible. (Stephanie)
Data: $\Delta S_{total} = 0$ at equilibrium. (Stephanie)

[3:34 - 10:54]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 9a
Claim: Can't really draw conclusions about dq_{surr}. (Garrett)
Data: *dH surrounding is exact function because H is a state function but q is path function. (Garrett)*
Warrant: *The fact that you equate them doesn't tell you very much. (Garrett)*
Rebuttal: *In this case right? (Dr. Green)*
Rebuttal Claim: dq_{surr} is an exact differential in this case. (Mark/Garrett)
Rebuttal Data: At constant pressure, $dH_{surr} = dq_{surr}$ (POGIL Materials, CTQ 9a)
Rebuttal Warrant: *So in the general case dq surroundings is not an exact differential but this is not a general case because of your equation. (Dr. Green)*
Rebuttal Qualifier: Under constant pressure and temperature. (Garrett)

[8:16 - 8:37]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 9a
Claim: $dH_{surr} = dq_{surr}$ (Mark)
Data: Equations from Model 2 (pg 96) (Mark/POGIL Materials)

[13:04 - 14:12]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 9c
Claim: $\Delta S = \Delta H_{surr}/T$ (Garrett)
Data: $dS = dq_{rev}/T$, $dH_{surr} = dq_{surr}$ (Garrett/POGIL Materials)
Warrant: *So you have dS equals dq surroundings over temperature, and the equation you earlier, and since we just said in (9)a that dH surroundings equals dq surroundings, we can substitute that in. And then take a derivative I mean the integral. (Stephanie)*

[17:09 - 17:40]
SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 10a
Claim: $\Delta S_{tot} = \Delta S_{sys} + \Delta H_{surr}/T$ (Stephanie)
Data: ΔS_{surr} in terms of ΔH_{surr} (Mark)
Warrant: You just have to substitute. (Stephanie)

[41:44 - 42:11]

SGW 10/21/2013 ChemActivity T6: Entropy, CTQ 12b
Claim: Entropy increases with increasing temperature. (Mark)
Data: More spontaneous. (Jacob)
Warrant: *I can't figure out how it would be true based on those equations so I was just making a like, it's a gut kind of thing.*

[3:15 - 4:58]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 1
Claim: I guess constant pressure, and equilibrium are the conditions. (Jacob)
Data: dS = dq/T (POGIL Materials)
Rebuttal: 1 doesn't have to be constant pressure. (Mark)

[6:10 - 6:53]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 2
Claim: It is spontaneous. (Mark)
Data: dS > dq/T (POGIL Materials)

[6:36 – 6:53]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 1
Claim: It's at equilibrium. (MArk)
Data: dS = dq/T (POGIL Materials)
Warrant: So it's reversible. (Stephanie)

[10:01 - 10:59]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 3
Claim: dw < -dS/T + dU (Mark)
Data: First law (POGIL Materials)
Data: dS > dq/T (POGIL Materials)

[11:11]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 4
Claim: A is a state function. (Stephanie)
Data: A = U - TS (POGIL Materials)
Warrant: U and S are state function. (Stephanie)

[13:51]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 4
Claim: dU = dq at constant volume (Stephanie)
Data: dw = -PdV, dU = dq + dw (implied)
Warrant: If it's constant volume, then you know dw = 0. (Stephanie)

[18:28]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 5
Claim: $\Delta A = 0$. (Jacob)
Data: Spontaneous process, constant T and V (POGIL Materials)

Warrant: Know dU = dq + dw and U = 0. (Jacob)

[21:06 – 21:40]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 4c
Claim: ΔA = ΔU – TΔS (Stephanie)
Data: dA = dU - TdS (answer to 4b)
Warrant: Just take the integral. (Stephanie)
Rebuttal: So you have work somewhere, in that equation. (Dr. Green)

[22:43- 26:31]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 4c
Claim: dA = -dw (Jacob)
Data: dA = dU - TdS (answer to 4b)
Data: dU - TdS = dw (Garrett/Dr. Green)
Warrant: *Because that's really dU minus q for dq and the right-hand side is really dw, right?* (Dr. Green)
Warrant: dq + dw = dU, and dU - TdS and if you have constant temp this is... I get that from that well dU, well the dU will just be equal to dw, in this case. (Jacob)
Rebuttal: What you just need to maintain, the inequality up there see you can't have = (Mark)
Rebuttal Claim: ΔA = 0. (Garrett)
Rebuttal Data: *But if dU minus TdS = dw then that means w = U - TS,* (Garrett)
Rebuttal Warrant: *So if no work is done then w =, which mean U - TS = 0 which means ΔA = 0.* (Garrett)
Rebuttal: *But this came from the inequality.* (Stephanie)
Rebuttal Claim: ΔA > Δw (Mark)
Rebuttal Data: unclear from transcript (related to rebuttal data, warrant, and rebuttal above)
Rebuttal Warrant: yeah and then you get that thing which is the same as that thing so you can substitute the dw or no dA into that inequality

[27:52 - 27:59]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 5
Claim: ΔA > 0 (Stephanie)
Data: Constant volume. (Stephanie)
Warrant: *Because if its constant volume then dw is just 0.* (Stephanie)

[29:24 - 29:42]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 6
Claim: TS is negative. (Jacob/POGIL Materials)
Data: U - TS (POGIL Materials)
Warrant: Because that's equal to work. (Garrett

[30:02]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 7a

Claim: G is a state function. (POGIL Materials)
Data: Because A and PV are state functions. (Mark)

[34:53 -]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 7c
(This is actually the solution to 7d, assumes constant T when shouldn't)
Claim: $\Delta H - T\Delta S = \Delta G$
Data: $H = U + PV$, $\Delta G = w$ (Stephanie)
Warrant: Substitute U in here, and then move these over to the side, and then take the integral. (Stephanie)

[40:45]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 7d
Claim: $\Delta G = \Delta H - T\Delta S$ (Mark)
Data: $dG = dH - TdS$ (Mark)
Warrant: *Because they are all state functions you can write them as ΔS.* (Mark)

[52:03 - 53:02]
SGW 10/21/2013 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 10
Claim: $\Delta G < 0$ (Garrett)
Data: *You still have to relate it to entropy.* (Garrett)
Warrant: *So the equation that we just got was Δ G less than or equal to 0, but I can't be equal to 0 because it spontaneous.* (Stephanie)

Small Group Work Argumentation Log for 12/13/2013

[21:14 - 21:41]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 2
Claim: Neon would have a higher temperature than N_2 upon input of the same amount of energy (Qi)
Data: It has like bonds (Qi)
Warrant: So the bonds would absorb some energy (Qi)

[25:20 - 26:33]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, Table/CTQ 3/4 (?)
Claim: Gas will have a lower heat capacity. (Qi/Melody)
Data: Particles in liquid could move around very well. (Qi)
Warrant: Heat is stored in terms of translational motion for liquids. (Jacob/Mark)
Rebuttal: Then it would have a higher temperature. (Mark)
Backing: No, but intermolecular forces are stronger. (Jacob)

[29:52 - 31:36]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 4
Claim: Water has a greater heat capacity. (Mark)
Data: You need to add more energy to water to increase its temperature. (Mark)

Warrant: *I said that the liquid is going to use some of the heat to overcome the intermolecular forces between the [molecules]*. (Melody)

[45:52 - 48:44]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 7a
Claim: w = P_{ext}dV for reversible expansion. (Mark/context)
Data: Replace P_{int} with P_{ext} (Mark)
Warrant: *We don't use the integral part because we're taking the derivative of work so it's just equal to PdV…I think*? (Mark)

[53:58 - 54:58]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 7f
Claim: dH = CpdT (Mark/Qi) Data: dH = dq_p (Qi)
Data: Cp = dq_pdT (Mark)
Warrant: Substitute dq_p with dH/dT (Mark)

[5:38 - 6:06]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 13
Claim: Δ U = 0 (Qi)
Data: It is isothermal. (Melody/book)
Warrant: Because isothermal means Δ T is zero. (Melody)

[6:26 - 7:12]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 12
Claim: Δ U = CvdT (Melody)
Data: Isothermal (dT = 0) (Qi)
Warrant: For an ideal gas, the energy only depends on the temperature. (Melody)

[9:33]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 11
Claim: Both partial derivatives of U holding temperature constant are zero. (Mark) Data: The internal energy would not change. (Mark)

[16:21 - 17:11]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 13
Claim: Δ U = 0 (Qi)
Data: Isothermal, Δ T = 0 (Melody)
Warrant: For an ideal gas, the energy is only dependent on temperature. (Melody)
Backing: They really want us to know that energy is only a function of temperature. (Melody)

[28:18 - 29:23]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, Table 3
Claim: bar=a + bT + c (Book)
Data: Cp is temperature dependent. (Melody)

Warrant: Within certain temperature ranges, you consider the parameters a, b, and c to solve for Cp.
(Melody)

[39:31 - 41:35]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 13
Claim: The energy of an ideal gas is a function of the temperature only. (Dr. Green)
Data: Temperature is a direct measure of how fast the of the average kinetic energy. (Dr. Green) Data: Ideal gas does not have forces between particles. (Melody)
Warrant: But if there are no forces between the particles, which is what an ideal gas is, we assume there are no forces between the particles, that means there is no potential energy, so every energy change is a kinetic energy change, so it al goes back to the fundamental idea of what an ideal gas is. (Dr. Green)
Backing: Some thermal energy can go into vibrational and rotational modes, but most goes into translational modes (Dr. Green)

[56:48]
SGW 12/13/2013 ChemActivity T4: Heat Capacity, CTQ 16
Claim: Δ H varies with temperature. (Melody)
Data: Cv and Cp vary with temperature. (Melody)
Warrant: Δ H depends on Cv and Cp, so it varies with temperature too. (Melody)

Small Group Work Argumentation Log for 12/16/2013

[0:00 - 20:22]
SGW 12/16/2013 ChemActivity T5: Temperature Dependence of the Enthalpy of Reaction, CTQ 2
Claim: Δ_rH will be different for a typical reaction at different temperatures. (Melody, Mark, Qi) Data: Heat capacity of products is different than heat capacity of reactants. (Melody)
Warrant 1: *Because the heat capacity for both reactants and products are different at different tempera- tures so ΔH will also be different. (Qi)*
Warrant 2: *But if we like increase the temperature, then the enthalpy of the reactants changes and then we do the reaction and then the enthalpy of the reactants goes down to here, but we still have to get the same change in enthalpy, so if this change is then equal to this change, this change isn't equal to this change (Melody)*
Backing: *I think just because I mean Cp would vary for both of them, so the difference between Cp would change too, I mean the magnitude would (Mark)*
Rebuttal (to Warrant 2): *I mean the enthalpy of both products and reactants changes at different tempera- tures so like the difference is also changing assuming the they are changing by the same amount.* (Qi)
Response to Rebuttal: *Yeah but if the heat capacity of the, so I guess, it's basically that the change in en- thalpy of the products going from here to here is different than the change in enthalpy of the reac- tants going from here to here, which I've got my stuff on the wrong side of the equation, but it still makes sense. (Melody)*

[11:22 - 12:25]

SGW 12/16/2013 ChemActivity T5: Temperature Dependence of the Enthalpy of Reaction, CTQ 1
Claim: *Enthalpy increases when the temperature increases.* (Melody) Data: $\Delta H = Cp\,\Delta T$ or the … (Melody)
Warrant: *The expression was like enthalpy of products at Temperature 2 minus enthalpy of products at temperature 2. (Mark)*

[25:32-28:14]
SGW 12/16/2013 ChemActivity T5: Temperature Dependence of the Enthalpy of Reaction, CTQ 3
Claim: *So is the integral from T2-T1 the negative of the same one from T1 to T2?* (Qi)
Rebuttal: *Yes, but the Cp is gonna be different, so this one is the Cp of the products and this is the Cp of the reactants* (Melody)
Rebuttal Data: $\Delta H =$ (Implied)
Rebuttal Warrant: *It's the ΔCp during the course of the reactants so that would be the ΔCp of the products minus the ΔCp of the reactants* (Melody)

[25:05]
SGW 12/16/2013 ChemActivity T5: Temperature Dependence of the Enthalpy of Reaction, CTQ 4
Claim: $d\Delta_r H = \Delta_r C_p dT$.
Data: *So we do a reaction at one temperature, compare that to a reaction at a different temperature and if we know how the heat capacity changes with temperature, or in both the reactants and the prod- ucts* (Dr. Green)
Warrant: *You can simplify this down a little bit more by recognizing that this T1 has to be the same as this T1 and so you can flip this integral and then you can have two things with the same limits of inte- gration integrating over the same thing, you can just subtract what's inside the integral, and so sometimes you'll see it written that way, so that will be a ΔCp where Δ refers to the change in heat capacities for the reaction. (Dr. Green)*

[58:17 - 59:01]
SGW 12/16/2013 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 4
Claim: $dS = C_v dT + P dV$ over T (Mark) Data: $dU = C_v dT$ (implied)
Warrant: *We just substitute this one into dU and then rearrange this equation right here.* (Mark)

[5:54 - 6:44]
SGW 12/16/2013 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ ??
Claim: Define dS in terms of Cp instead of Cv. (Mark) Data: $C_p - C_v = R$ for an ideal gas. (Mark)
Warrant: *No we need Cp in there, but we need to go to Cp from Cv because this has Cv in it* (Mark) Rebuttal: *Actually I don't think this part involves the previous part.* (Qi)
[Continued with no resolution]

[14:56 - 18:52]
SGW 12/16/2013 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 7/8
Claim: dS = Cp/T dT - R/P dP (Qi) Data: dH = dU +VdP + PdV (Qi)
Data: dH = CpdT (Qi)
Data: dU = TdS - PdV (Qi)
Warrant: *So you just rearrange…It's just doing algebra with all the d stuff.* (Qi)

[45:56 - 47:01]
SGW 12/16/2013 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 11
Claim: It is impossible to determine what will happen to the value of Δ r S when you raise the tempera- ture. (Melody)
Data: ΔrS T2 - ΔrS T1 = ΔrCp ln T2/T1 (book)
Warrant: It depends on whether the natural log of T2/T1 is greater or less than 1. (Melody)
Backing: *Or even if it's not such a tiny amount, if it's much bigger, because like the natural log of 1.5 is less than 1. (Melody)*

[5:30 - 6:31]
SGW 12/16/2013 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 14
Claim: ΔH surroundings = -ΔH system.
(Qi/Dr. Green) Data: Pressure is constant.
(Dr. Green/book)
Warrant: ΔH= qp (Dr. Green)
Backing: q is always between system and surroundings. (Dr. Green)

Appendix B: Classroom B Argument Logs

Small Group Work Argumentation Log for 9/1/2010

[4:39 - 4:55]
SGW 9/1/2010 ChemActivity T1: Work, FQ
Claim: Work is being done. (Thaddeus)
Data: The piston moves. (Thaddeus)
Warrant: Instead of pressure increasing, weight is decreasing. (Thaddeus)

[5:09 - 06:05]
SGW 9/1/2010 ChemActivity T1: Work, FQ
Claim: Work is being done by the system. (Thaddeus)
Data: The system is expanding, pushing the weight up. (Thaddeus)
Data: The system is losing pressure. (Jerome)
Warrant: As pressure decreases, the gas [volume] is able to increase. (Jerome)

Small Group Work Argumentation Log for 9/8/2010

[05:38]
SGW 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 4a
Claim: Negative work on system. (Summer)
Data: Temperature and height increase. (Summer)
Warrant: Increased area in system. (Summer)

[26:13]
SGW 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 11a
Claim: For a constant volume process, dw = pressure. (Caprice)
Data: Volume is constant. (Caprice)
Warrant: So the derivative of the constant is the coefficient of the expression (PdV). (Caprice)
Rebuttal Claim: For a constant volume process, dw = 0. (Quentin).
Rebuttal Data: If dV is zero, (PdV). (Quentin)
Rebuttal Warrant: *If you have a constant volume, there's no change, which means no change—* (Quentin)

[28:58]
SGW 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 11b
Claim: $dU_{sys} = dq$ (Caprice)
Data: Constant volume process (Quentin)
Data: $dU = dq + dw$ (CTQ8)
Warrant: $dw = 0$ (Caprice)

[47:45 - 50:37]
SGW 9/8/2010 ChemActivity T3: Enthalpy, FQ
Claim: The energy change of the two containers will be the same. (Quentin)
Data: Diagram, page 61, adding heat to the system (POGIL Materials)
Rebuttal: *They didn't say they added temperature though. Same amount of it. No, pressure's not constant, volume isn't cause this…* (Caprice)
Rebuttal Claim: Energy change will not be the same in both systems. (Caprice and Quentin)
Rebuttal Data: One system will have constant volume and one will have constant pressure. (Quentin)

Rebuttal Warrant: *Constant volume counts as more energy, there's gonna be more energy, cause if the volume's small, the pressure is going to increase very well. But if this increases, then pressure will become constant. (*Caprice*)*

Small Group Work Argumentation Log for 9/15/2010

[20:02]
SGW 9/15/2010 ChemActivity T3: Enthalpy, CTQ 8
Claim: Negative sign for enthalpy indicates that energy is given off. (Jerome)
Data: It is exothermic, bonds forming. (Thaddeus)
Warrant: Bonds formed are more energetically stable than bonds broken, so you are in a more stable situation afterwards. (Jerome/Callum)

[20:02]
SGW 9/15/2010 ChemActivity T3: Enthalpy, CTQ 9
Claim: The enthalpy change will be the positive (opposite of the first reaction.) (Thaddeus/Jerome)
Data: $H_2(g) + ½\ O_2(g) \rightarrow H_2O(l)$ $\Delta_rH^o = -285.83$ KJ/mol (POGIL Materials)
Warrant: Just flip it around. (Thaddeus)

[20:02]
SGW 9/15/2010 ChemActivity T3: Enthalpy, CTQ 10
Claim: ΔH for $H_2O_{(l)} \rightarrow H_2O_{(g)}$ = difference between two heats of formation (44.01 kJ/mol). (Jerome and Callum)
Data: $H_2(g) + ½\ O_2(g) \rightarrow H_2O(l)$ $\Delta_rH^o = -285.83$ KJ/mol
$H_2(g) + ½\ O_2(g) \rightarrow H_2O(g)$ $\Delta_rH^o = -241.82$ KJ/mol (POGIL Materials)
Warrant: The top equation needs to be flipped because you start with liquid water, flip it so the net equation would end with gas. (Thaddeus/Callum)
Backing: A positive value makes sense since you are vaporizing the water. (Thaddeus/Jerome)

[29:27]
SGW 9/15/2010 ChemActivity T3: Enthalpy, CTQ 12
Claim: C and F are a result of the reaction of the elements that compose it. (Thaddeus/Callum/POGIL Materials)
Data: All the reactions from the POGIL Materials
Equation C: $Mg(s) + C(s) + 3/2\ O_2(g) \rightarrow MgCO_3(s)$ (POGIL Materials)
Equation F: $C(s) + O_2(g) \rightarrow CO_2(g)$
Warrant: All the other reactions have molecules. (Thaddeus/Callum)
Rebuttal: *So C and F? But it also has a molecule. It's got carbon monoxide*. (Callum)
Warrant: *well it's the CO gas. CO gas there is elemental. I would say O_2 would be elemental, because it's the stable state of Oxygen.* (Thaddeus)

[33:37]
SGW 9/15/2010 ChemActivity T3: Enthalpy, CTQ 13

Claim: All the reactions are enthalpy of formation reactions except d. (Thaddeus/POGIL Materials)
Data: Chemical Equations, Model 4, page 67 (POGIL Materials)
Warrant: D is a decomposition reaction. (Callum)
Rebuttal Claim: D is still an enthalpy of formation reaction, so why wouldn't they all be? (Jerome)
Qualifier: *It depends on how you define the difference between heat of reaction and heat of formation.* (Thaddeus)
Rebuttal Data: reaction D from POGIL Materials
Rebuttal Warrant: *But this one, you're still making two things. So even though it's a decomposition, you're still making … you know two moles out of one*. (Ron)

[35:00]
SGW 9/15/2010 ChemActivity T3: Enthalpy, CTQ 13
Claim: *I think it's c and f, the same as in CTQ 12.* (Thaddeus)
Data: Chemical Equations, Model 4, page 67 (POGIL Materials)
Warrant: *Yeah, cause those are the only ones that involve only stable state elements in the formation.* (Callum)
Backing: Definition of enthalpy of formation produces 1 mole of product from the elements. (Thaddeus)

[44:57 - 45:17]
SGW 9/15/2010 ChemActivity T3: Enthalpy, CTQ 16
Claim: *Bonds formed minus bonds broken.* (Thaddeus)
Data: ????
Rebuttal: Is that what you did to do the calculation? (Dr. Black)
New Claim: uh, so it's equal to the sum of the heats of formation or the products minus the heats of formation of the substituents, or reactants. (Jerome/Thaddeus/Dr. Black)

[54:15]
SGW 9/15/2010 ChemActivity T3A: Enthalpy, FQ
Claim: Weight will be raised. (Jerome)
Data: The reaction produces more moles. (Jerome)
Warrant: *It's energetically favorable, so it's exothermic or releasing heat. Since you're losing energy, that tends to be when the system does work.* (Jerome)
Backing: *it's a combustion reaction, so we know it's exothermic.* (Callum)

[01:02:00]
SGW 9/15/2010 ChemActivity T3A: Enthalpy, CTQ 3
Claim: q for the process is positive. (Jerome)
Data: Heat is gained by the system. (Callum and Thaddeus)
Warrant: *Cause it's absorbing.* (Thaddeus)

Small Group Work Argumentation Log for 9/20/2010

[3:19]
SGW 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 7
Claim: There are two moles of gas before the chemical reaction occurs. (Rosalind)
Data: Model 2, page 73 (POGIL Materials)
Warrant: 1 mole of Gas A and 1 mole of Gas B (Rosalind)

[3:19]
SGW 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 9
Claim: $\Delta_r n_{gas} = 1$ (Summer)
Data: Model 2, page 73 (POGIL Materials)
Warrant: $\Delta_r n_{gas}$ = product – reactants = 3-2 (Rosalind)

[17:42]
SGW 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 13
Claim: The piston would move less. (Rosalind)
Data: Cause the reaction is exothermic. (Rosalind)
Warrant: Some of the energy would go into the surroundings. (Rosalind)
Rebuttal Claim: The piston would move up. (Summer)
Rebuttal Data: ΔH is less than zero, negative H is exothermic. (Summer/Rosalind)
Rebuttal: *Well if it would move less cause some of the energy that would move the system up is now going to taking heat for the system*. (Rosalind)
Warrant: *But unless it's saying just cause it's exothermic meaning the movement alone could be the energy change, doesn't have to be heat change. It could be the same more or less. Cause exothermic just means the work was done on the surroundings, right?* (Rosalind)

[17:42]
SGW 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 14
Claim: The piston moves less. (Jerome)
Data: Model 2, page 73 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrow C(g) + 2D(g)$ $\Delta_r H = 0$
Data: CTQ 14 Chemical Equation: $A(g) + B(g) \leftrightarrow C(g) + D(g)$ $\Delta_r H < 0$ (POGIL Materials)
Warrant: There is no change in moles [in eq'n 14] (Brown)
Request for Clarification: *Less moles of gas produced. That's our reasoning?* (Summer)
Warrant restated: *Yes, well, the equal amount. No change in mole.* (Jerome)
Rebuttal: $\Delta n = 0$, *so it doesn't move.*

[17:42]
SGW 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 15
Claim: *Piston should lower?* (Summer)
Data: Model 2, page 73 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrow C(g) + 2D(g)$ $\Delta_r H = 0$

Data: CTQ 15 Chemical Equation: $A(g) + 2B(g) \leftrightarrow C(g) + D(g)$ $\Delta_r H < 0$
(POGIL Materials)
Warrant: *Well you're going from more volume to less volume.* (Rosalind)

[33:19]
SGW 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 18
Claim: This is not a constant temperature process. (Jerome)
Data: Model 3, page 76 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrow C(g) + D(g)$ $\Delta_r H < 0$
Rebuttal: *I thought it was.* (constant pressure) (Thaddeus)
Rebuttal Data: ΔH *is less than zero so it's exothermic.* (Summer)
Rebuttal Warrant: *the heat change was from the chemical reactions, just not from the surroundings, but it's still a heat change.* (Rosalind)

[33:19]
SGW 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 22
Claim: Work is negative. (Rosalind)
Data: Model 3, page 76 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrow C(g) + D(g)$ $\Delta_r H < 0$
Warrant: The system does the work. (Rosalind)
Clarification: Work = -PdV (Summer)

[33:19]
SGW 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 23
Claim: Two sources for any work that may be done are: Changes in temperature, and changes in moles. (Rosalind/Jerome)
Data: *Cause we're saying that* $dw = p \Delta v$. *and that* $p \Delta v = -rt \Delta n$, *so change in moles, change in temp*. (Rosalind)

[42:17]
SGW 9/20/2010 ChemActivity T4: Heat Capacity, FQ
Claim: Temperature of resulting mixture is less than 65 (Summer)
Data: The masses are the same (Brown)
Warrant: Water has a very high specific heat compared to anything else, so there will be little change (Summer)
Rebuttal Claim: The answer is e) unable to determine without knowing densities. (Rosalind)
Rebuttal Data: Information from FQ, Page 79 (POGIL Materials)
Rebuttal Warrant: we need the specific heat numbers to determine the heat (Rosalind)

[49:05]
SGW 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 2
Claim: Neon would be hotter that N_2. (Summer)
Data: Neon doesn't have any bonds. (Summer)

Warrant: Nitrogen has bonds, bonds can devote energy to, stretching, straining, and you've also got rotational and those other types of motion. Whereas the Neon has just translational. (Summer)

[01:01:48]
SGW 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 3
Claim: The heat capacity of neon is 20 J/mol (Summer)
Data: Table 1, page 80 (POGIL Materials)

[01:01:48]
SGW 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 4
Claim: Table 1 is ranked in order from highest to lowest molar heat capacity as show. (Rosalind/Summer)
Data: Table 1, page 80 (POGIL Materials)
Data: Heat capacity of neon is 20 J/mol (answer to Q3) the heat capacity of water is 4.18 J/mol. (recall)
Warrant: Cause it would be increasing as it goes down. It goes from 20 to 4.18. (Rosalind)
Rebuttal Claim: We have reversed it. (Summer)
Rebuttal Data: *Specific heat is just in relation to water. Heat capacity is the amount of energy required to raise one mole by one degree.* (Summer)
Rebuttal Warrant: *So twenty joules is what this requires, so like three times as much. So we were just looking at it backwards.* (Summer)

Small Group Work Argumentation Log for 9/22/2010

[17:21]
SGW 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 9
Claim: A bomb calorimeter could be used to determine Cv. (Jerome)
Data: *You're using something you have to maintain at constant volume* (Jerome)

[24:49]
SGW 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 11
Claim: $\partial U/\partial P)_T$ & $\partial U/\partial V)_T = 0$ (Jerome)
Data: *U is a function of T only and T is held constant.* (Jerome)
Warrant: *The energy of an ideal gas is a function of temperature only. So the energy of the system is only dependent on temperature, so U with respect to T, T constant, is still zero*. (Jerome)

[43:24]
SGW 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 15

Claim: *The statement* [The more complex the species the larger is Cp^o and the larger in Cp^o with increasing temperature.] *appears to be somewhat true*. (Thaddeus)
Data: Table 4, page 88 (POGIL Materials)
Qualifier: With the exception of monatomic hydrogen. (Rosalind)
Data for Qualifier: *Maybe, the fact that it's a gas instead of a solid* (Jerome)
Rebuttal: *But H_2 is a gas. The only difference is that it's monatomic instead of diatomic.* (Rosalind)
New Claim: Cp increases with temp, so long as b and c are really small. (Thaddeus/Rosalind)
Data: Table 4, page 88 (POGIL Materials)
Warrant: *Well Cp increase with temperature is true right?* (Thaddeus)

[58:23]
SGW 9/22/2010 ChemActivity T5: Temperature Dependence of Enthalpy of Reaction, CTQ 1
Claim: ΔH [for changing temp of products] is non-zero. (Jerome)
Data: Heat capacities are different. (Jerome)

[58:23]
SGW 9/22/2010 ChemActivity T5: Temperature Dependence of Enthalpy of Reaction, CTQ??
Claim: $\Delta H = Cp\Delta T$ (Thaddeus)
Data: $\Delta H = \int Cp\Delta T$ at constant pressure (Jerome/Thaddeus)
Warrant: *Then we just pull out constants.* (Rosalind)
Rebuttal: *But we just argued now that the Cps are actually different for different temperatures* (Jerome)
Data: *This is a constant pressure, right? Yeah, Cp's constant, so I don't why that'd be different. Oh wait, wait, wait. Maybe they're wanting us to include reactants and products.* (Jerome)

[58:23]
SGW 9/22/2010 ChemActivity T5: Temperature Dependence of Enthalpy of Reaction, CTQ 2
Claim: Δ H is different for a different chemical reaction at a different temperature. (Jerome)
Data: Cause Δ H varies and Cp varies at different temperatures. (Jerome/Rosalind)

Small Group Work Argumentation Log for 9/27/2010

[1:28]
SGW 9/27/2010 ChemActivity T6: Entropy, FQ
Claim: *I guess the temperature of the brick is gonna drop and the temperature of the water is gonna increase*. (Rosalind)

Data: The first law of thermo – energy is neither created nor destroyed. (implicit)
Warrant: *It's just the exchange of energy, isn't it? The brick loses energy and the water finds it*? (Rosalind)
Rebuttal: *I don't know if it must decrease to be consistent with the law though.* (Jerome)
Claim: The first law doesn't apply to the statement (When a hot brick is dropped into cold water, the temperature of the brick must decrease to be consistent with the first law of thermodynamics.) (Jerome)
Backing: The temperature of the brick must decrease if the temperature of the water increases. (Rosalind/Jerome)

[18:35]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 2a
Claim: ΔS total is positive. (Rosalind)
Data: $(S_{tot})_{final} > (S_{tot})_{initial}$ (POGIL Materials)
Warrant: Final minus initial. (Jerome)

[18:35]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 3c
Claim: The reverse of the process where $(S_{tot})_{final} < (S_{tot})_{initial}$ is spontaneous. (Rosalind)
Data: $(S_{tot})_{final} > (S_{tot})_{initial}$ (POGIL Materials)
Warrant: *If the inequality applies, the process is irreversible. If the equality applies, the process is reversible at equilibrium. So at zero, it's reversible, but negative—* (Rosalind)
Rebuttal: *I don't think it means, it's irreversible in terms of (Rosalind: yeah, but it's positive) all these equalities of pressure or whatever. So the process is reversible, it will occur naturally.* (Jerome)
Rebuttal Claim: Yes the reverse process is spontaneous. (Jerome)
Rebuttal Data: $(S_{tot})_{final} > (S_{tot})_{initial}$ (POGIL Materials)
Rebuttal Warrant: *It's the reverse process. So the reverse of this one. If this is gonna increase in, or decrease in entropy, then they had to add energy to put it into that state.* (Jerome)

[18:35]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 4b
Claim: No the process is not spontaneous. (Jerome)
Data: $(S_{tot})_{final} = (S_{tot})_{initial}$ (POGIL Materials)
Warrant: *It's at equilibrium, well no it's already at equilibrium. It's spontaneously at equilibrium at equilibrium.* (Jerome)

[18:35]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 4c
Claim: No the reverse process is not spontaneous. (Jerome)
Data: $(S_{tot})_{final} = (S_{tot})_{initial}$ (POGIL Materials)
Warrant: It's at equilibrium. (Jerome)

[31:38]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 6a
Claim: The brick and the water are the system. The enclosure would be the surroundings. (Jerome)
Data: A hot brick is tossed into cold water in an adiabatic enclosure. (POGIL Materials)
Warrant: Cause they're in contact, and there's no heat exchange enclosure. (Jerome)

[31:38]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 6b
Claim: The temp of the brick goes down, the temp of the water increases. (Jerome)
Data: A hot brick is tossed into cold water in an adiabatic enclosure. (POGIL Materials)
Data: 2nd law of thermos. (implicit)
Warrant: The system will equilibrate, the surrounding will remain constant. (Jerome)

[31:38]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 6c
Claim: No 6b, is not based on an application of the 1st law of thermo.
Data: The 1st law of thermos (implicit)
Data: A hot brick is tossed into cold water in an adiabatic enclosure. (POGIL Materials)
Warrant: *It doesn't have to change and no direction to change according to the first law or implied by first law.* (Jerome)

[31:38]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 6d
Claim: ΔU is zero. (Jerome)
Data: No heat is lost. (Jerome)
Rebuttal: Or no energy lost? (Rosalind)
Reply: No heat. (Jerome)

[31:38]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 6e
Claim: Yes CTQ 6b (A hot brick is tossed into cold water in an adiabatic enclosure. The temperature of the brick will decrease and the water will increase) on the 1st law of thermo. (Jerome)
Data: The 1st law of thermos
Warrant: There is conservation of energy. (Rosalind/Jerome)

[31:38]
SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 6f
Claim: ΔS is positive, there would be an increase in entropy. (Rosalind/Jerome)
Data: *Because you're spreading the heat energy of the brick into a larger volume.* (Jerome)
Warrant: *The deconcentration of heat from the brick, you're increasing entropy of the total*. (Jerome)

Backing: *The heat of the brick is being distributed to not only the brick, but in the water as well*. (Rosalind)

[31:38]

SGW 9/27/2010 ChemActivity T6: Entropy, CTQ 8

Claim: Irreversible processes are spontaneous. (Jerome)

Data: *Cause that would be your* Δ *S universe is greater than or equal to zero. Or greater than zero* (Jerome)

Rebuttal*: Does it have to be spontaneous*? (Dr. Black)

Claim: No. An irreversible process does not have to be spontaneous. (Brittany)

Warrant: All spontaneous processes are irreversible, but not all irreversible processes are spontaneous. (Dr. Black/Jerome).

[59:23]

SGW 9/27/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, FQ

Claim: The difference in entropy of a gaseous and liquid water increase as temperature increases. (Jerome)

Data: dq/T = dS (Jerome)

Warrant: *So the difference in S is the difference, but it doesn't say. So, if the difference is positive, then the change in S is positive*. (Jerome)

Rebuttal Claim: *I think it's gonna increase, but does like gas increase more than liquid.* (Rosalind)

Rebuttal Claim: *I don't think it's comparing the two. So I think it's gonna increase based off of this equation.* (Jerome)

Rebuttal Data: *Because the change in entropy plus the change in heat.* (Jerome)

Rebuttal Data: *You have to add heat to increase temperature.* (Rosalind)

Rebuttal Claim: Wouldn't it be negative. (Jerome)

Rebuttal Data: *Cause for an exothermic process, then the q is negative*. (Jerome)

Rebuttal: *Well the system's not releasing heat, it's gaining* heat. (Rosalind)

Rebuttal Claim: dS would increase (inaud) (Rosalind)

Rebuttal Data: *because if dq increases then t is going to increase, they're both gonna go up. But will they go up proportionately where they're gonna stay the same*? (Rosalind)

Rebuttal: *That's not what it's asking. The difference between gas and a liquid water increases. Uh, they're not comparing liquid water and gases*. (Jerome)

Small Group Work Argumentation Log for 9/29/2010

No arguments were generated during small group work on 9/29/2010

Small Group Work Argumentation Log for 10/4/2010

[9:41 - 10:12]
SGW 10/4/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 12
Claim: ΔH positive for phase transition from solid to liquid at 231K. (Jerome/POGIL Materials)
Data: $H_2O(s) \longleftrightarrow H_2O(l)$ (POGIL Materials)
$\Delta_r H_{273} = 6025$ J/mol
$\Delta_r S_{273} = 22.1$ J/K mol
Warrant: Constant temperature or constant pressure. (Summer)
Rebuttal: Those should be constant for a phase change. (Jerome)
Claim: ΔH is positive. (Jerome)
Data: Temperature is constant. (Jerome)
Warrant: You must add energy to have phase change. (Jerome)

[10:47 - 11:03]
SGW 10/4/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 12
Claim: Entropy is positive. (POGIL Materials)
Data: $H_2O(s) \longleftrightarrow H_2O(l)$ (POGIL Materials)
$\Delta_r H_{273} = 6025$ J/mol
$\Delta_r S_{273} = 22.1$ J/K mol
Data: Process is spontaneous. (Callum)
Warrant: Entropy is positive for spontaneous process. (Rosalind)
Rebuttal: Entropy is negative for spontaneous process. (Jerome)
Rebuttal: You are thinking of Gibbs Free Energy. (Summer)
Backing: Yeah, it's decreasing entropy. (Jerome)

[11:42 - 11:57]
SGW 10/4/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 13
Claim: $\Delta S = \Delta H/T$ at 1 bar (Jerome)
Data: $\Delta_r H_{273} = 6025$ J/mol (POGIL Materials)
Warrant: 0.6025/273 (Jerome)
Rebuttal: Did you need to do the math? (Thaddeus)
Claim: $\Delta H_{sys}/T$ goes to 0 at equilibrium. (Thaddeus)
Data: The process occurs at 0 degrees. (Thaddeus)
Warrant: The change of ΔH for the system is $\Delta H_{system}/T$ (Thaddeus)

[12:36 - 13:15]
SGW 10/4/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 14
Claim: S_{surr}=-22.1 (Thaddeus)
Data: $\Delta_r H_{273} = 6025$ J/mol (POGIL Materials)

$\Delta_r S_{273}$ = 22.1 J/K mol
Data: At equilibrium, so $S_{tot} = 0$ (Thaddeus)
Warrant: In order for $S_{tot} = 0$ because it is at equilibrium, S_{surr} = -22.1 (Thaddeus)

[21:07 - 21:34]
SGW 10/4/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 14
Claim: ΔS_{sys} =22.1 (Jerome)
Data: $\Delta C_p = 0$ (Jerome)
Warrant: There is no change in the change in entropy (Jerome)
Rebuttal: But wouldn't that (ΔS_{system}) be negative? (Callum)
Claim: ΔS_{system} = -22.1 (Callum)
Data: Cp = 0 (Callum)
Rebuttal: Change in Cp = 0, not Cp = 0 (Jerome)

[51:29 - 54:31]
SGW 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, FQ
Claim: All entropies are positive. (Group/ question)
Data: Entropy has absolute zero, 3rd law. (Callum/Jerome)
Warrant: At zero, there is no movement. It is impossible to go less than no movement. (Thaddeus)
Backing: Even solid state is jiggling and vibrating. (Thaddeus)

[57:08 - 57:30]
SGW 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 1
Claim: All materials must be solids at absolute zero. (Thaddeus/question)
Data: Definition of a solid is no molecular movement. (Thaddeus/Jerome)
Warrant: Because the lower you go [temperature], the less movement there is. (Thaddeus)

[58:04 - 58:19]
SGW 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 2
Claim: As temperature increases, entropy increases because of molecular movement. (Jerome/Summer)
Data: Definition of a solid is no molecular movement. (Jerome)
Because the lower you go [temperature], the less movement there is. (Summer)
Warrant: Because you have more distributed energy states. (Thaddeus)

[1:01:07 - 1:01:42]
SGW 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 3
Claim: Entropy has a non-negative value. (POGIL Materials)
Data: 3rd law (POGIL Materials)
Warrant: Because there is no movement at 0 K. (Thaddeus)
Backing: If zero means no movement, you can't have less than no movement. (Jerome/Thaddeus)

[1:02:33 - 1:03:04]
SGW 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 4
Claim: Entropy changes gradually, then abruptly at phase change because of temperature. (Group/Question)
Data: $\Delta S = Cp \frac{T_2}{T_1}$, Graph page 108 (POGIL Materials)
Warrant: Because temperature increases, so there is more movement. (Thaddeus)

[1:03:18 - 1:03:34]
SGW 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ Q5
Claim: T' is the melting point, T'' is the boiling point. (Thaddeus)
Data: Graph on page 108 (POGIL Materials)

Small Group Work Argumentation Log for 10/6/2010

[29:21 - 29:28]
SGW 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 11
Claim: The entropies in Table 1 are positive. (POGIL Materials)
Data: Table 1, page 111 (POGIL Materials)
Warrant: Because they are all absolute entropies. (Jerome)

[45:46 - 49:07]
SGW 10/6/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, FQ
Claim: The reaction occurs. (Thaddeus)
Data: Formation of 'this' is positive, larger bond strengths. (Jerome/Thaddeus)
Warrant: Bond strengths outweighs entropy lost. (Jerome)
Backing: Reaction would be spontaneous. (Thaddeus)

[57:35 - 01:02:25]
SGW 10/6/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 3
Claim: dw = or < dU - TdS (Jerome)
Data: First law, dU = dq + dw (Summer)

Small Group Work Argumentation Log for 10/13/2010

No arguments were generated during small group work on 10/13/2010

Small Group Work Argumentation Log for 10/18/2010

[16:22 – 18:45]
SGW 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 4b

Claim: $\partial G/\partial T)_P = -S$ (Jermone)
Data: dG = VdP - SdT (POGIL Materials)
Warrant: *Well this dT, well if t is held constant then that one is just VdP so that one* ΔP *T equal VdP alright, and then I'm guessing the visa versa GdT P held constant* then you just get equals negative S. (Jermone)

[41:11- 43:14]
SGW 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 6b
Claim: $d\bar{G}$ = RTlnP/P° (Jermone/Rosalind)
Data: dG = VdP, V = nRT/P (ideal gas law) (Jermone)
Warrant: Divide both sides by n and it drops off. Integrate from P° to P. dG with bar shows what we did with n. (Jermone/Rosalind)

[51:25 - 54:22]
SGW 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 8a
Claim: $\mu_{H2\ pure}=\mu_{H2\ mix}$ (Jermone/Rosalind)
Data: Diagram page 122 (POGIL Materials)
Warrant: *If thats a partial pressure the pressure should be the same on both sides, but you got this N2 in there also see what im saying so thats going to be throwing your pressure off. The N2 cant go across but its still going to be taking up volume so it is just the partial pressure of N2 H2 going to be the same or just the pressure of H2 be the same or mix.* (Jermone)
Rebuttal Claim: $\mu_{H2\ pure}<\mu_{H2\ mix}$ (Jermone)
Rebuttal Data: Chemical potential is in terms of G/n (Jermone)
Rebuttal Data: Diagram page 122 (POGIL Materials)
Rebuttal Warrant: As n increases, whole value of chemical potential gets smaller. (Jermone)
Rebuttal Backing: The assumption is that pure H_2 has more moles than mixed H_2. (Rosalind)

Small Group Work Argumentation Log for 10/20/2010

[7:09 – 8:24]
SGW 10/20/2010 ChemActivity T11: Equilibrium, FQ
Claim: Pressure will increase. (Thaddeus)
Data: $PCl_5(g) \leftarrow \rightarrow PCl_3(g) + Cl_2(g)$ (POGIL Materials)
Warrant: Going from 1 mole to 2 moles. (Rosalind)
Rebuttal: No it says that they are all put into the container, So we won't know until you know what the equilibrium constant is as far as your gas volumes are. (Jerome)
Claim: The pressure will reach equilibrium. (Jerome)

[17:00 – 17:33]
SGW 10/20/2010 ChemActivity T11: Equilibrium, CTQ 1
Claim: 1 mole N_2 consumed, 3 moles of H_2 are consumed, 2 moles of NH_3 are produced (Rosalind)
Data: $N_2(g) + 3\ H_2(g) \leftarrow\rightarrow 2\ NH_3(g)$ (POGIL Materials)
Warrant: 1 mole of reaction occurs and when you talk about a mole of reaction you are talking about the stoichiometric coefficient as written. (Dr. Black)

[19:17 – 20:08]
SGW 10/20/2010 ChemActivity T11: Equilibrium, CTQ 2
Claim: The number of mole present of each species are ξ moles of reaction are zero, zero, two. (Thaddeus)
Data: $N_2(g) + 3\ H_2(g) \leftarrow\rightarrow 2\ NH_3(g)$ (POGIL Materials)
Warrant: 100% product formed, therefore you aren't going to have any reactants. (Thaddeus)
Rebuttal: *Not everything has to react, after a certain amount of time*. (Dr. Black)

[30:40 – 31:31]
SGW 10/20/2010 ChemActivity T11: Equilibrium, CTQ 3a
Claim: $dnN2/d\xi = -1$
$dnH2/d\xi = -3$
$dnNH3/d\xi = +2$ (Jerome)
Data: $nN_2 = n_oN_2 - \xi$
$nH_2 = n_oH_2 - 3\xi$
$nNH_3 = n_oNH_3 + 2\xi$ (POGIL Materials, Answer to CTQ 2)
Warrant*: essentially I just took, your dni, ...yah so you end up with -1 over 1, -3 over 1, and 2 over 1* (Ron)

[35:24 – 36:18]
SGW 10/20/2010 ChemActivity T11: Equilibrium, CTQ 3d
Claim: i is proportional to absolute value of Vi (Rosalind)
Data: Vi is negative for reactant, Vi is positive for products, Vi is the stoichiometric coefficient of component i. (POGIL Materials, Answers to CTQ 3b and 3c)
Warrant: the greater the positive value means the more product, the greater the negative means the more reactant (Rosalind)

[1:01:52 – 1:06:16]
SGW 10/20/2010 ChemActivity T11: Equilibrium, CTQ 7
Claim: $\Delta H = 131$ KJ/mol
$\Delta S = -134$ KJ/mol
$\Delta G = 91.1$ KJ/mol
Data: Table 1, page 131 (POGIL Materials)
Warrant: $\Delta H = (-111)-(-242)$ = products - reactants
$\Delta S = 134 + 198 – 189 - 5.7$ = products – reactants

$\Delta G = 131 - (298)(0.134) = \Delta H - T\Delta S$

Whole Class Discussion Argumentation Log for 9/1/2010

[6:55 - 8:30]
WCD 9/1/2010 ChemActivity T1: Work, FQ
Claim: Work is done and it is done by the system. (Quentin)
Data: Volume of gas increases. (Kayden)
Warrant: After the weight moves up, it has a higher potential energy. If potential energy was put into the system, then work was done. (Parker)
Backing: According to the physics definition of work, work is a force applied over a distance. In chemistry, we take the point of view of the system so if the system does work, work is negative; if work is done on the system, work is positive. (Dr. Black)

[10:32 - 11:08]
WCD 9/1/2010 ChemActivity T1: Work, CTQ 1
Claim: Work is negative when work is done by the system. (Dr. Black/Francis)
Data: Work is negative because pressure is lost. (Francis)
Warrant: Pressure is like force, so force was lost resulting in negative work. (Francis)

[11:33 - 11:55]
WCD 9/1/2010 ChemActivity T1: Work, CTQ 2
Claim: Upon compression, work is positive. (Dr. Black/Reed)
Data: Gas is compressed resulting in increasing pressure. (Reed)
Warrant: Work is identified by looking at the way things are being pushed. (Dr. Black)

Whole Class Discussion Argumentation Log for 9/8/2010

[5:47 - 5:57]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 4a
Claim: Work is done. (Dr. Black/Jahara)
Data: Because the piston moves. (Jahara)
Warrant: The movement of the piston is the change in Δh [height]. (Jahara)

[6:13 - 6:17]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 4a
Claim: Work on system is negative. (Jahara)
Data: Piston is raised. (Jahara)
Warrant: It was done by the system. (Jahara)

[06:24 - 7:46]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 4b
Claim: Magnitude of work increases. (Jerome)
Data: *More heat is supplied by the surroundings*. (Dr. Black/POGIL Materials)
Warrant: There is a positive and increased Δa [area]. (Jerome)
Alternate Claim: The magnitude of work is decreasing. (Brandon)
Alternate Data: Heat is supplied to the system. (Dr. Black)
Alternate Warrant: The value becomes a larger negative number when work increases. (Sam/Brandon)
Resolution: Magnitude of work done increases. (Dr. Black)
Data: Work is a larger negative number. (Dr. Black)
Warrant: When looking at magnitude, you consider the absolute value. (Dr. Black)

[8:07 – 8:25]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 5a
Claim: The potential energy of the mass increases. (Parker)
Data: Height increases. (Parker)
Warrant: ν = mgh, *Because they are directly proportional. If one side increases then the other side has to increase*. (Parker)

[08:37 - 8:53]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 5b
Claim: E = mgΔh (Parker)
Data: The only energy changes for the mechanical surroundings are associated with changes in the position of the weight. (POGIL Materials)
Warrant: *Because the mass is going to stay the same, gravity stays the same, but the heights would change.* (Parker)

[10:16 - 11:39]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 5c
Claim: $\Delta U = P_{ext}\Delta V$ (Quentin)
Data: Pressure equals force over area. (Caprice)
Data: Force is pressure times area. (Caprice)
Warrant: Combining Δh with h will give volume. (Caprice)
Warrant: You substitute force for mg. (Dr. Black)

[12:06 - 12:50]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 6a
Claim: External pressure is constant for the process. (Aiden)
Data: System is reversibly changing. (Aiden)
Data: Volume is changing. (Aiden)
Rebuttal: *Those are true statements, it does not lead me to believe that it's constant external pressure though.* (Dr. Black)
Data: Atmospheric pressure (1 atm) is constant. (Aiden)

Warrant: So if you are doing it against atmospheric pressure, the atmospheric pressure will not change if you heat the system. (Aiden/Dr. Black)

[13:06 - 13:46]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 6b
Claim: The pressure of the system is constant for the process. (Aiden)
Data: The system is reversible. (Aiden)
Warrant: So the total energy is constant. (Aiden)
Rebuttal: *That's true, but it doesn't have anything to do with…* (Dr. Black)
Warrant: *Because the system is in equilibrium.* (Aiden)
Backing: *That's what "reversible" means is the system is in the equilibrium throughout the process*. If it's in equilibrium, then the internal pressure and my external pressure have to be equivalent. (Dr. Black)

[15:08 - 15:14]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, Model 2
Claim: When system receives heat, it warms up. (Male)
Data: Temperature increases. (Male 2)

[15:21 - 15:30]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, Model 2
Claim: The system cools down. (Class)
Data: System loses heat. (Class)

[16:20 - 16:41]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, Model 2
Claim: q is positive. (Dr. Black/Class)
Data: Temperature increases. (Class)
Warrant: Heat is absorbed. (Class)

[16:28 - 16:33]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, Model 2
Claim: q is negative. (Dr. Black/Class)
Data: Temperature decreases. (Class)
Warrant: Heat is being released. (Dr. Black/Class)

[17:22 - 18:19]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, Model 2
Claim: Energy is transferred from weight to water (Male 2)
Data: Weight lowers/Diagram and info in POGIL Materials (POGIL Materials)
Warrant: ???? "stripping the vent"

[20:47 - 22:07]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 8
Claim: dU = dq - dw (Jahara)

Data: Model 2, page 55 (POGIL Materials)
Warrant: It was just a change, we treat it as a positive and a negative. (Jahara)

[20:47 - 22:07]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 8
Claim: dU = dq - dw
Data: Model 2, page 55 (POGIL Materials)
Warrant: Work will be negative (Elise)
Rebuttal: Work done by itself? (Aiden)

[22:17 - 22:59]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 8
Claim: Equation on board (assumed to be dU=dq + dw) (Aiden/Male)
Data: Model 2, page 55 (POGIL Materials)
Warrant: *So the total is going to be the amount of heat plus the work done by the system.* (Aiden)
Rebuttal: *Since the system is doing the work, we decided to put a negative number.* (Aiden)
Rebuttal Claim: The sign for heat and work should be the same. (Male)
Rebuttal Data: Work and heat should have the same sign convention. (Male)
Rebuttal Warrant: *Because if you have negative work, regardless if it's positive in the equation, it's going to be negative.* (Quentin)

[35:28 - 35:48]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 10c
Claim: $dU_{sys} = -PdV$ (Aiden)
Data: In an adiabatic system, dU = dq + dw, dq = 0, dw = -PdV (POGIL Materials, Answers to CTQ 8, CTQ 10a, and CTQ 10b)
Warrant: *So for an adiabatic system where dq = 0, then the change in energy comes from changes due to work.* (Dr. Black)

[36:01 - 36:50]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 11b
Claim: $dU_{sys} = dq$ (Class Boards)
Data: dU = dq + dw, dw = 0 (POGIL Materials, Answers to CTQ 8, CTQ 11a)
Warrant: For a constant volume process, no work is done, so the work term goes to zero. (Dr. Black/Class)

[42:22 - 43:17]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 14
Claim: Work is state function. (Male)
Data: recalled definition???? (Male)
Warrant: Using the ball analogy, if ball does not move, there is no work done. (Male)
Claim's Rebuttal: No its very much path dependent.

Warrant's Rebuttal: Energy in that situation would be released as heat, not force distance work. (Dr. Black/Male)

[44:16 - 45:21]
WCD 9/8/2010 ChemActivity T2: The First Law of Thermodynamics, CTQ 15
Claim: $\Delta U_{tot} = 0$ at equilibrium (Caprice)
Data: ΔU_{total} = universe system + universe surroundings (Quentin/Male)
Data: Equilibrium is when ΔU_{system} equals $\Delta U_{surroundings}$. (Caprice)
Rebuttal: $\Delta U_{tot} = 0$ always (Dr. Black)
Warrant: Energy is conserved (1^{st} law of thermodynamics) (Dr. Black/Caprice)

[51:33 - 52:15]
WCD 9/8/2010 ChemActivity T3: Enthalpy, FQ
Claim: The change in energy will not be the same. (Dr. Black/Class)
Data: The one with stops has fixed volume. (refers for model) (Aiden)
Warrant: *So the system* [on the right] *doesn't use energy to work*. (Aiden)
Rebuttal: *Shouldn't there be more to that?* (Quentin)

[52:19]
WCD 9/8/2010 ChemActivity T3: Enthalpy, FQ
Claim: Pressure increases. (Quentin)
Data: Fixed volume. (Quentin)
Warrant: Your gas molecules are moving at a faster velocity, they have more energy. (Quentin)

[53:48 – 53:54]
WCD 9/8/2010 ChemActivity T3: Enthalpy, FQ
Claim: The first system is more likely to have work done. (Class/Dr. Black)
Data: Diagram, page 61. Energy change/ add heat/ have dq. (POGIL Materials/Class)
Warrant: So since I don't have anything holding the piston down, it going to try and stay in equilibrium where the internal and external pressure are the same. (Dr. Black)

[54:18 – 54:30]
WCD 9/8/2010 ChemActivity T3: Enthalpy, FQ
Claim: ΔU is not the same for both systems. (Dr. Black/Elise)
Data: Because q is same for both systems. (Dr. Black)
Data: *But work is not the same*. (Class)
Warrant: q for both systems is the same, but work is different. So ΔU_{sys} will be different for each. (Dr. Black/Class)

[55:49 – 56:06]
WCD 9/8/2010 ChemActivity T3: Enthalpy, CTQ 1a
Claim: PV is a state function. (Class)
Data: P is finalized potential, V only concerned with the change in volume, final minus initial. (Dr. Black/Class)

[56.06]
WCD 9/8/2010 ChemActivity T3: Enthalpy, CTQ 1b
Claim: H is a state function. (Class)
Data: H = U + PV (POGIL Materials)
Warrant: It is a sum of state functions P, V, and U. (Liam)

[1:02:10 - 1:02:31]
WCD 9/8/2010 ChemActivity T3: Enthalpy, CTQ 7
Claim: ΔH for a reaction does not depend on mechanism. (Female)
Data: It is a state function. (Caprice)
Warrant: It only depends on itself (final and initial). (Caprice and Dr. Black)

[1:03:04]
WCD 9/8/2010 ChemActivity T3: Enthalpy, Information
Claim: Bond-breaking is exothermic. (Class)
Data: *You need to absorb energy to form a bond,* (Caprice)
Warrant: *I think the opposite, the reverse is the case, to break it.* (Caprice)
Warrant: *The way I see it is, a bond has a lot of energy in it, so if you break it, wouldn't it release it?* (Quentin)

[1:04:35 - 1:06:19]
WCD 9/8/2010 ChemActivity T3: Enthalpy, General Discussion
Claim: Bond breaking is always endothermic, bond formations is always exothermic. (Dr. Black)
Data: Bonded atoms are lower energy than the separate atoms. (Dr. Black)
Warrant: All processes are driven by energetic favorability (Dr. Black/Class)
Backing: Consider the potential energy well, the bond is at the energy minimum and it takes energy to separate it. (Dr. Black)

Whole Class Discussion Argumentation Log for 9/15/2010

[00:24 - 01:17]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 3
Claim: At constant pressure, dH = dU + PdV (Aiden)
Data: $dH = dU + dPV + dVP$ (Aiden)
Warrant: At constant pressure, differentiation of pressure is zero (Aiden)

[2:42 - 7:15]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 4
Claim: dH = dq (Elise)
Data: $dw = -P_{ex}dV$ (Elise)
Data: dH = dU + PdV (POGIL Materials, Answer CTQ 3)

Warrant: *I fit the, not really canceling, this would become 0, eliminating that. So then I basically took this down, and what I did was put this equation back in for this line. So it's this term, I want to say cancelled.* (Elise)

[07:36]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 5a
Claim: $\Delta H = \Delta U + P\Delta V$ (Jerome)
Data: $dH = dU + PdV$ (Jerome)
Warrant: All variables are state functions, so upon integration, they are all delta. (Jerome)

[08:50 - 11:29]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 5b
Claim: $\Delta H = q + w$ (Caprice)
Data: $\Delta H = U + PV$ and $\int dH = \Delta H$ & $dq = q$ (Caprice)
Warrant: (PV term goes to zero because P is constant), $U = q + w$ is substituted into U of the previous equation. (Caprice)
Rebuttal: Where did that one delta come from. (Male)
Warrant 2: S*ince w was close to q because u was a constant q because, w, there's no w in the equation so I couldn't do delta. H equals just q because U is not the final one q*. (Caprice)
Rebuttal: *I would make qU - w for your substitution*. (Male 2)
Rebuttal: *Have you already accounted for the q + w relationship to get to equation 4*? (Male 3)
Instructor reframes the analysis

[11:49 - 12:13]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 5b
Claim: PV = 0 (Caprice)
Data: Because P is constant. (Caprice)
Warrant: P didnt change. (Caprice)
Rebuttal: So P is constant, does it mean it's 0? (Dr. Black)
Rebuttal: dP is zero (Caprice/Dr. Black)
Rebuttal Claim: $\Delta H = q$ (Dr. Black)
Rebuttal Data: $H = U + PV$, $dU = dq + dw$, $dw = -PdV$ (Dr. Black)
Rebuttal Warrant: $dH = dU + PdV + VdP$ (pressure is constant, so VdP goes to zero). dU equation is substituted for dU, so $dH = dq + dw + PdV$. $-PdV$ is substituted for dw in the equation. $dH = dq - PdV + PdV$. You integrate both sides, which gives $\Delta H = q$.

[16:49 - 17:30]
WCD 9/15/2010 ChemActivity T3: Enthalpy, Model 3
Claim: We do not have to worry about path of a reaction. (Dr. Black/POGIL Materials)
Data: because ΔH is a state function. (Female)
Warrant: State functions only depend on start and finish point, not path. (Dr. Black/Class)

[25:12 - 25:33]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 8
Claim: Forming bonds releases energy. (Liam)
Data: Model 3, page 66 (POGIL Materials)
Warrant: *I guess, formation of electrons in the nuclei are energetically favorable aspect*. (Liam)
Rebuttal: *Not the formation of the electrons in the nuclei, the interaction.* (Dr. Black)

[26:21 - 26:30]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 8
Claim: *Energy was given off, and the reaction was exothermic*. (Jamal)
Data: Model 3, page 66 (POGIL Materials)
Warrant: *Bonds formed are more energetically stable than bonds broken.* (Jerome)

[27:15]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 10
Claim: $\Delta H = 44.01$ (Aiden)
Data: Model 3, page 66 (POGIL Materials)
Warrant: We did final minus initial. (Aiden)

[36:52 - 37:58]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 11
Claim: All reactions form one mole of product except d, so d does not represent the enthalpy of formation. (Dr. Black/Class)
Data: Equations from Model 4, page 67 (POGIL Materials)
Warrant: Equation D is destroying ($BaCO_3(s) \rightarrow BaO(s) + CO_2(g)$) (Caprice)
Alternate Claim: *We said C and E* (Reed)
Alternate Data: Model 4, page 67 (POGIL Materials)
Alternate Warrant: *Because those are fractions, you have to multiply those to get one mole of that.* (Reed)
Rebuttal Claim: *Right, but read the question again: Is 1 mole of compound produced?* (Dr. Black)
Rebuttal Data: d forms two moles of products. (Dr. Black,/Aiden)

[38:12]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 12
Claim: Reactions C and F the products are the results of the reaction of the elements that compose it. (Rosalind)
Data: Chemical Equations, Model 4, page 67 (POGIL Materials)
Equation C: $Mg(s) + C(s) + 3/2\ O_2(g) \rightarrow MgCO_3(s)$
Equation F: $C(s) + O_2(g) \rightarrow CO_2(g)$
Warrant: *They're made up of elements that there is no, the other ones are not.* (Rosalind)
Warrant Clarified: *Right, they've got compounds, it's not just elements*. (Rosalind/Dr. Black)

[38:30 - 39:10]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 13
Claim: C and F are enthalpy of formation reactions (Rosalind)
Data: Chemical Equations, Model 4, page 67 (POGIL Materials)
Equation C: $Mg(s) + C(s) + 3/2\ O_2(g) \rightarrow MgCO_3(s)$
Equation F: $C(s) + O_2(g) \rightarrow CO_2(g)$
Warrant: The components of enthalpy formation are 1 mole of product and all the reactants are elements, they are in their stable states, and it's not heated. (Jamal/Dr. Black)

[49:32]
WCD 9/15/2010 ChemActivity T3: Enthalpy, CTQ 15
Claim: $\Delta H = -100.6$ KJ (class)
Data: Chemical Equations and Enthalpy of Formation Data, CTQ 15, page 68 (POGIL Materials)
Warrant: The sign of the heat of formation for the first two equations is switched. (Elise)
Backing: *If you take 2 negative numbers, they're going to become a positive anyway*. (Elise)
Request for clarification: Why did you change the signs? (Dr. Black)
Warrant: In order for the reactants to be reactants, equations must be flipped. (Dr. Black/Brandon/Elise)
Backing: Sign must switch if equation is being flipped. (Dr. Black/Brandon/Caprice)

[56:54 - 57:33]
WCD 9/15/2010 ChemActivity T3A: Enthalpy, FQ
Claim: The weight would be raised. (Class)
Data: More moles of gas are produced then reacted. (Jerome)
Data: Diagram, page 71 (POGIL Materials)
Warrant: When this (data) happens, system is exothermic. The energy that is lost tends to do work. (Jerome)
Alternate Claim: The weight will be lowered. (Caprice/Aiden)
Rebuttal: More moles of product results in increased volume. (Dr. Black)
Alternate Data: Hydrogen bonding higher intermolecular force. (Aiden)
Alternate Warrant: Higher intermolecular force, lowering the pressure, lowers the piston. (Aiden)

[1:03:44 - 1:04:24]
WCD 9/15/2010 ChemActivity T3A: Enthalpy, CTQ 1
Claim: Process is a constant pressure system. (Class)
Data: External pressure is always the same. (Caprice)
Data: Model 1, page 72 (POGIL Materials)
Warrant: *We got the weight sitting here, we're not changing anything, we haven't locked it.* (Dr. Black)

[1:04:24 - 1:04:47]

WCD 9/15/2010 ChemActivity T3A: Enthalpy, CTQ 2
Claim: Process is not a constant temperature process. (Class)
Data: Heat is lost as the weight is raised. (POGIL Materials/Rosalind)
Warrant: *It increases the molecules.* (Jamal)

[1:04:48 - 1:06:03]
WCD 9/15/2010 ChemActivity T3A: Enthalpy, CTQ 3
Claim: q is positive for the process. (Aiden)
Data: *Because a gas is heated up its volume...* (Aiden)
Alternate Claim: q is negative. (Jamal)
Alternate Data: Work is done on the system. (Jamal)
Rebuttal: *Look at your diagram again, the surroundings is your brick, the system is your gas.* (Dr. Black)
Claim: q is positive. (Quentin)
Data: System gain heat from the brick. (Quentin/Caprice/Dr. Black)
Warrant: If it gains heat the sign it positive. (Quentin/Dr. Black)

Whole Class Discussion Argumentation Log for 9/20/2010

[11:00 – 11:20]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 5
Claim: This is a constant pressure process. (Callum)
Data: Model 2, page 73 (POGIL Materials)
Warrant: The weight doesn't come off, external pressure is always the same (Reed)

[11:30 – 11:38]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 6
Claim: This is a constant temperature process (Class/board)
Data: Model 2, page 73 (POGIL Materials)
Warrant: *the bath and the surroundings remain constant temp, so it should make the whole thing isothermal*. (Jerome)

[12:02 – 12:28]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 7
Claim: The reaction started with 2 moles (Class/Dominique)
Data: Model 2, page 73 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrows C(g) + 2D(g)$ $\Delta_r H = 0$
Warrant: *There's one on each, the reactants, plus underneath the diagram, it says 1 mole gas A and 1 mole gas B*. (Dominique)

[12:25 – 12:35]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 8
Claim: There are 3 moles of gas in the container after the reaction (Class/Quentin)

Data: Model 2, page 73 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrows C(g) + 2D(g)$ $\Delta_r H = 0$
Warrant: *You have 2 moles of D and you have 1 of C* (Quentin)

[12:46 – 15:48]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 10
Claim: $P\Delta V = RT\Delta n$ (Class)
Data: know that $PV = nRT$ (Dr. Black/Class)
Warrant: Therefore $\Delta(PV) = \Delta(nRT)$, and PRT are held constant. (Dr. Black/Class)

[16:20 – 16:51]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 11
Claim: The piston rises. (Class)
Data: Model 2, page 73 (POGIL Materials)
Data: Volume increases (Reed)
Warrant: More particles or more moles of the substances. (Reed)
Backing: $P\Delta V = RT\Delta n$, volume and moles are directly proportional. (Dr. Black)

[16:53 – 17:07]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 12
Claim: w is negative for this process. (Class)
Data: Model 2, page 73 (POGIL Materials)
Warrant: *The piston moves up, the system probably did work, which means it's negative, loss of ability to do further work*. (Francis)

[26:05 – 27:41]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 13
Claim: The piston is going to move the same as the piston in Model 2. (Quentin)
Data: Model 2, page 73 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrows C(g) + 2D(g)$ $\Delta_r H = 0$
Date: CTQ 13 Chemical Equation: $A(g) + B(g) \leftrightarrows C(g) + 2D(g)$ $\Delta_r H < 0$ (POGIL Materials)
Data: *Work = RT* Δn *negative* (Quentin)
Warrant: *So if your moles aren't changing it's the only thing really determining, the same amount of work, your pistons are going to be the same*. (Quentin)
Alternate Claim: *The piston would move less, and less work would be done*. (Jerome)
Alternate Data: Reaction is exothermic, releasing heat ($\Delta H < 0$) (Jerome)
Alternate Warrant: *The ability to do work as energy is the same as heat. If loss of heat is energy, so losing some of your energy as heat, would mean you have less energy to do work* (Jerome)
Alternate Claim: The piston moves more (on the board)
Alternate Data: $\Delta H = 0$ in Model 2, page 73, $\Delta H < 0$ in CTQ 13 (POGIL Materials)
Alternate *I was thinking about it as going from an equilibrium process of H = 0 to an exothermic process, and H is positive*. (Male 2)
Alternate Warrant: The temperature would increase, raising the volume (Francis)

Rebuttal: But we have a constant temperature bath to absorb any heat that's released by the reaction. So the fact that it's exothermic doesn't change our system at all. (Dr. Black/Class)
Claim: *So in terms of the behavior of the gas, it's going to be exactly the same as it was in our first one*. (Dr. Black)
Data: Model 2, page 73, and information from CTQ 13, and constant temperature. (POGIL Materials)
Warrant: *So if we weren't controlling the temperature, then yes, you would expect it to expand even more, because now you've changed the moles AND you've changed the temperature. But we've rigged the system*. (Dr. Black)

[28:27 – 29:21]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 14
Claim: The piston will move less than the piston in Model 2. (Kayden)
Data: Model 2, page 73 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrow C(g) + 2D(g)$ $\Delta_r H = 0$
Date: CTQ 14 Chemical Equation: $A(g) + B(g) \leftrightarrow C(g) + D(g)$ $\Delta_r H < 0$ (POGIL Materials)
Warrant: There's no change in volume (Kayden)
Clarification: $\Delta PV = 0$, *that means that nothing on the right can change either. So what 2 things have to be constant?* (Dr. Black)
Warrant: There is no change in number of moles, and we rigged our system to be constant temperature, so there is no change in volume. (Kayden/Dr. Black)

[29:29 – 29:38]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 15
Claim: The piston moves down. (Class)
Data: *If there's less moles of product than there is of reactants.* (Dominique)
Warrant: *Therefore your* Δn *is equal to negative 1*, *and which is proportional to* $P\,\Delta V$, *so it goes down.* (Dominique)

[32:22]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, Model 3
Claim: Any heat change in the system must be due to chemical reaction. (Dr. Black)
Data: System is adiabatic. (Dr. Black)
Warrant: No heat exchanged with surroundings. (Dr. Black)

[37:02 – 37:16]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 17
Claim: This is a constant pressure process. (Class)
Data: Model 3, page 76 (POGIL Materials)
Chemical Equation: $A(g) + B(g) \leftrightarrow C(g) + D(g)$ $\Delta_r H < 0$
Warrant: *Temperature is the same as last time, your weight doesn't change, so your pressure is the same.* (Reed)

[37:21 – 38:05]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 18
Claim: This is a constant temperature process. (Kayden)
Data: Model 3, page 76 (POGIL Materials)
Warrant: *It's constant temperature because it's kept constant.* (Kayden)
Rebuttal: I thought there was a change in temperature. (Male)

[38:14 – 39:05]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 18
Claim: This is a constant temperature process. (Reed)
Data: *Because it says that no temperature can leave the system*. (Reed)
Rebuttal: It doesn't say 'no temperature', it says "No heat is transferred." (Dr. Black/Aiden)
Alternate Claim: This is not a constant temperature process. (Jerome)
Alternate Data: Model 3, page 76 /System is adiabatic (POGIL Materials)
Alternate Warrant: *The reaction can be exothermic or endothermic, so you could have temperature gain or decrease, you just can't exchange that heat to the surroundings, only lose it through work or other chemical means.* (Jerome)
Alternate Backing: *It says that it's exothermic, so heat's released inside the system. And there's no heat exchange with the surroundings, then the temperature of the system has to increase.* (Dr. Black)

[39:23 – 39:40]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 19
Claim: The temperature increases. (class)
Data: Model 3, page 76 (POGIL Materials)
Data: Heat is not able to escape into the surroundings. (Kayden)

[40:02 – 40:13]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 20
Claim: This is an adiabatic process. (Class)
Data: Model 3, page 76 (POGIL Materials)
Warrant: It tells you there is no heat exchange. And you know the temperature's changing, so it can't be isothermal (Quentin).

[40:19 – 40:32]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 21
Claim: The piston moves up (Class)
Data: Model 3, page 76 (POGIL Materials)
Warrant: *Because your temperature is increasing, the piston has to go up, because your volume is increasing, because temperature increases.* (Reed)

[40:39 – 41:21]
WCD 9/20/2010 ChemActivity T3A: Enthalpy, CTQ 22
Claim: w is negative for this process. (Class)

Data: Model 3, page 76 /Temperature increases.(POGIL Materials/Answer to Q19)
Warrant 1: *Our reasoning was, work is related to temperature involved, so temperature, it's proportional to the temperature being involved to some extent, so as the temperature was released, the process, the work, the negative of that, work was negative.* (Jerome)
Warrant 2: *You could have done the point of view that the system is expanding; therefore, by our definition, work would be negative*. (Dr. Black)

[45:19 – 45:52]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, FQ
Claim: The temperature of the resulting mixture is < 65 °C. (on boards)
Data: *Since we have equal masses.* (Quentin)
Warrant: *Technically we'll have more moles of water, and we know that water has more attractive intermolecular forces.* (Quentin)
Alternate Warrant: *The specific heat of water is higher so it will change less as energy is transferred, so it'll be closer to the water side, which was < 65 degrees. (*Jahara*)*

[47:10 - 47:52]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, Model 1
Claim: Adding heat changes temperature (Dr. Black)
Data: Heat increases average kinetic energy (Male)
Warrant: Temperature is defined in terms of motion and velocity of particles. (Reed)
Backing: More specifically, temperature defined as distribution of energy of molecules. (Dr. Black)

[53:28 – 54:19]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 1
Claim: Energy absorbed to increase kinetic energy doesn't cause change in temperature (Jahara)
Data: Add energy to H_2O at 0 degrees and no change in temperature as it changes to H_2O(l) (Jahara)
Warrant: Because of phase transition, no temperature increase [latent heat] (Jahara/Dr. Black)
Qualifier: I was assuming under all conditions. (Jahara)
Rebuttal: No, it does not work for all conditions. (Dr. Black)
Counter Claim: Energy going into translational motion causes an increase in temperature. (Dr. Black/Jahara)

[54:50 – 57:01]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 2
Claim: The N_2 will be hotter? (Quentin board)
Data: Kinetic energy = 1 times nv squared, and N_2 weighs more than neon. (Quentin)
Warrant: *That if it weighs more, it's going to have a slower velocity. And since the term's v squared, and in that sense, we figure that the velocity would have more weight than the temperature.* (Quentin)

Alternate Claim: Ne is hotter. (Dominique's board)
Alternate Data: *Neon has less intermolecular forces.* (Dominique)
Alternate Warrant: *So more the heat would be going towards kinetic energy.* (Dominique)
Alternate Claim: Ne is hotter. (Reed's board)
Alternate Data: Because neon is lighter. (Reed)
Alternate Warrant: *It'll move faster with the same amount of heat added. And because there's triple bond between nitrogen. The amount of heat given in the system, part of it will be considered to break the bonds.* (Reed/Sam)
Rebuttal: *Oh, just because I heat up nitrogen gas, does it disassociate the bonds?* (Dr. Black)
Alternate Claim: Neon is hotter. (Jerome's board)
Alternate Data: *With the N_2, now you have different ways for it to move, plus devote energy towards the bond, be it vibrational, rotational versus not just translational movement and stuff.* (Jerome)
Alternate Warrant: *There are other ways to devote heat to it, it doesn't necessarily have the same increasing kinetic energy for that kind of input. You'd have more if your input of energy towards translational movement of the neon, so it was up for hotter average kinetic energy and hotter*. (Jerome)

[58:40 – 59:08]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 2
Claim: Nitrogen has a larger intermolecular force than Neon. (Class)
Data: *It's more polarizable, because it's larger*. (Jahara)
Warrant: It's a molecule, its more polarizable, its larger, therefore it can have more Vander Waals forces (Dr. Black)

[59:08 – 59:36]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 2
Claim: Neon will have a higher temperature. (Dr. Black)
Data: Because Nitrogen has bonds. (Jahara)
Warrant: *So the nitrogen can store some of that entropy or take some of that entropy and use it in vibrational energy, rotational energy, to go into up to different levels.* (Dr. Black)

[01:06:35]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 3
Claim: The molar heat capacity for Ne(g) is 20 J/K mol (board)
Data: Table 1, page 80 (POGIL Materials)
Warrant: *By definition, neon raised by 1 degree Celsius by giving it 20 joules per kelvin (*Dominique)

[1:06:49 - 1:06:59]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 4
Claim: $H_2O(l) > CH_4(g) > N_2(g) > Ne(g)$ is the order of molar heat capacities from highest to lowest. (board)

Data: Table 1, page 80 (POGIL Materials)
Warrant: *the same 20 joules only raised water .3 degrees, so it's just based off that you know it'll take a little over 3 times as much to raise it to 1 degree Celsius as it did neon.* (Jerome)

[01:07:21 – 01:07:40]
WCD 9/20/2010 ChemActivity T4: Heat Capacity, CTQ 5
Claim: The heat capacity for gaseous water would be less than the heat capacity for liquid water. (Class/Reed)
Data: *Because the gases move faster than water, or than liquids. Your hydrogen bond, your bonding between molecules would be less.* (Reed)
Warrant: *Therefore your heat capacity would be less, because there's no strong interaction between the molecules.* (Reed)

Whole Class Discussion Argumentation Log for 9/22/2010

[04:30]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 6
Claim: dU = CvdT [for a constant volume process] (Reed)
Data: *So we know that U = U(T,V).* (Reed)
Data: $dU = \partial U/\partial T)_V + \partial U/\partial V)_T\, dV$ (Reed)
Data: $\partial U/\partial T)_V = Cv$(Reed)
Warrant: *So we took dU equals; we held V constant, so it's dU over VT times dT. And we took, held d constant, and found d over dV times dV ... Contra dT, and that remained the same. They asked for when d, or I mean when your volume was constant, so dV = 0.* (Reed)

[06:40]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 7a
Claim: dwP = -PdV (Jerome)
Data: P internal = P external (Jerome)
Warrant: It's constant pressure, it's a reversible process. (Jerome)

[06:40 - 07:48]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 7e
Claim: $dH = dq_p$ (Jerome)
Data: dw = -PdV (Jerome)
Data: dU = dq + dw (Jerome)
Data: dH = dU + PdV (Jerome)
Warrant: Substitute for dw into dU expression resulting in dU = dq - PdV. A*nd then they wanted us to figure out what the dH was in this scenario, which is normally dU + PdV. I got the derivation for that, if you want to see it. But then substituting what*

dU was up here down here, you get the -PdV and PdV, canceling each other out, giving you just dq_p. So therefore dH = this dq, it could be q sub p. (Jerome)

[07:48 - 10:41]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 7f
Claim: *dHp = Cp dt* (Jerome)
Data: $dH = dq_p$ (Jerome)
Data: $dH/dT = dq_p/dT$ (Jerome)
Warrant: *Relate it to heat capacity, where pressure is constant, where you got this dq_p over dT, which is through that relationship analogous to this dH pressure constant dT or the partial derivative of H over dT with P constant.* (Jerome)
Rebuttal: dH_P not appropriate (Dr. Black)
Rebuttal Claim: dH = Cp dT (Jerome/Caprice/Dr. Black)
Rebuttal Data: H is a state function. (Jerome)
Rebuttal Warrant: Don't need condition for state function. (Dr. Black/Caprice)

[10:44 – 11:05]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 7
Claim: Don't need to label the conditions 'n' p. (Dr. Black)
Data: Because it's a state function. (Jerome)
Warrant: *But we don't put those labels on our variables most of the time because they're not path dependent.* (Dr. Black)

[11:54 - 13:42]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 8
Claim: dH = CpdT (Dominique)
Data: $dH = \partial H/\partial T)_P\, dT + \partial H/\partial P)_T\, dP$ (Dominique)
Data: $Cp = \partial H/\partial T)_P$ (Dominique)
Warrant: Pressure is constant, so second term goes to zero. (Dominique)
Warrant: And then substitution. (Dominique)
Rebuttal: You don't need the subscript P for Cp. (Caprice)
Rebuttal Claim: You do need to indicate the constant pressure process. (Male)
Rebuttal Data: It is not a state system. (Male)
Rebuttal Warrant: *Because it's, it's the heat capacity at a constant pressure, so, and that's how you're denoting it, that's what the Cp equals*. (Dominique)
Rebuttal Backing: *And since Cp and Cv are not equivalent, you have to know under what conditions the heat capacity arises.* (Dr. Black)

[19:03 – 21:47]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 9
Claim: A bomb calorimeter could be used to determine Cv. (Reed)
Data: By using a standard, then you know U.
Data: Bomb is constant volume (Reed)
Data: *Cv equals (writes (dU/dT)* (Reed/Dr. Black)

Warrant: *so you can solve for the change for U, or the, you can solve for the U over dT, so you can solve for the change in energy with respect to temperature …* {additional discussion} *Because you're going to make the temperature change. And you know what your change in energy is, because you know how much energy you put in, and assuming you know how much it used, then you know much is used.* (Reed)
Warrant: *We use the bomb because that gives me the process at constant volume.* (Dr. Black)
Request for clarification: *How would you know how much energy you used?* (Vick)
Clarification: Use standard mass to know how much internal energy there is. (Reed)
Rebuttal Claim: *You're not really accounting for base changes or difficult reaction processes*. (Jamal)
Rebuttal Data*: You're burning a substance so you're going to have combustion, you're going to be breaking down bonds and everything*. (Jamal)
Rebuttal Warrant: *So you're not really accounting for the molar heat capacity, isn't that just increasing the temperature of a substance by a certain amount*? (Jamal)
Rebuttal Claim: *Apply a certain amount of energy to a substance and measure the temperature change* [to determine heat capacity]. (Jamal)
Rebuttal Data/Warrant: *You need to know how much of the substance you have.* (Jamal)
Rebuttal Data/Warrant: *Assuming density doesn't change. He said the volume has to be constant.* (Male)

[21:54 – 22:38]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 10
Claim: Use a calorimeter open to the air to determine Cp. (Reed)
Data: Because atmospheric pressure shouldn't change during the process. (Reed)
Warrant: There you can assume pressure is constant when you calculate Cp. (Reed)

[26:32 – 27:09]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 11
Claim: Both are zero. (boards)
Data: Temperature is constant and it is an ideal gas. (Dominique)
Data: Energy is only dependent on temperature. (Dominique)
Warrant*: If you keep temperature constant, the derivative of energy is going to be 0.* (Dominique)
Rebuttal: *So say it again except we're not using the word 'derivative'.* (Dr. Black)
Warrant restated: *The change in energy when temperature is constant, is always going to be 0.* (Dominique)

[27:40 - 28:49]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 12
Claim: dU = Cv times the derivative of T for your ideal gas. (Quentin)
Data: $dU = \partial U/\partial T)_V + \partial U/\partial V)_T\, dV$ (POGIL Materials, Answer to CTQ 6)
Data: *Your derivative, or your partial derivative of u, with respect to your temperature, actually is your amount of heat capacity there.* (Quentin)

Warrant: *So we take the derivative of U equals the partial derivative in respect to energy, in respect to the partial derivative. Your temperature at constant volume. Plus your partial derivative of energy with respect to your partial derivative of volume at constant temperature. And then you end up canceling out this, because if it's at constant temperature, since u is a function of temperature, it's going to equal 0 ...* and then substitute for heat capacity. (Quentin)

[31:06 – 31:37]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 13
Claim: $\Delta U = 0$ for an isothermal process for an ideal gas in which the pressure increases from 1 bar to 10 bar. (boards)
Data: Isothermal process. (Male)
Warrant: $\Delta T = 0$, therefore $\Delta U = 0$ (Dr. Black)

[33:21 – 33:59]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, Model 4
Claim: Monoatomic gases' heat capacity are not temperature dependent. (Dr. Black/Class)
Data: Equation: $Cp = a + bT + cT^{-2}$ (POGIL Materials)
Table 3, page 85 (POGIL Materials)
Data: *For helium, neon, argon, krypton, and xeon, your b and c are both equal to 0, and those are the fully variable, the constants that are multiplied by T in your original*. (Jamal)
Warrant: b and c are 0 or they're very small, so we can make the assumption Cp=H. (Dr. Black/Jamal)
Qualifier: *If I've got any kind of significant value for b or c, then obviously there's going to have some temperature dependence*. (Dr. Black)

[47:30 – 49:30]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 15
Claim: *Not sure that the change* [in heat capacity with increasing temp] *is always larger for the more complex species* (Jerome)
Data: Table 4, page 88 (POGIL Materials)
Warrant: *It did seem to be more complex species, there was a larger initial value. Assuming in the case of hydrogen gas, it's ionized at that point, so it's the same amount of ionized gas, so I guess you can consider that complex. But the more interaction going on such, despite the fact that it's ionizing.* (Jerome)
Rebuttal: *It's not ionizing, it's just atomic hydrogen, so you don't have to, there's no charge on it.* (Dr. Black)
Alternate Claim: *We agreed with the statement* [The more complex the species the larger is Cp^o and the larger in Cp^o with increasing temperature.] (Dominique)
Alternate Data: Table 4, page 88 (POGIL Materials)
Qualifier: *The only exception is when you have small, uncomplex molecules, then it's not dependent on temperatures* (Dominique)
Alternate Claim: *the more complex does not necessarily mean larger.* (Reed)

Alternate Data: Table 4, page 88 (POGIL Materials)
Alternate Warrant: *carbon graphite would be more complex than hydrogen, just bigger molecule and everything. But it's got a lower cp.* (Reed)
Qualifier: Statement is true if you are comparing similar phases. (Dr. Black)

[50:13]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 16
Claim: The heat of reaction is temperature dependent. (Reed)
Data: The derivative of H = Cp dT (Reed)
Warrant: *Since that's dependent on temperature, that's your delta, that is your ΔH, so it would be dependent on temperature.* (Reed)

[51:02 – 54:35]
WCD 9/22/2010 ChemActivity T4: Heat Capacity, CTQ 16
Claim: This reaction {$H_2 + ½ O_2 \rightarrow H_2O$} does not have the same heat of reaction at 25°C and 100°C (Dr. Black/Class)
Data: Different phases. (Brandon)
Rebuttal: This is done in the gas phase. (Dr. Black)
Data: *No, because it's a different temperature raise. ΔH is a function of Cp in a wa.y* (Tice)
Rebuttal: *Stop and think about what you just said though.* (Dr. Black)
Claim: The two values are different because the heat of formations are slightly different. (Tice)
Data: *Each substance that you're looking at individually has a different heat capacity*. (Tice)
Warrant: *Each element, or each substance would have its own energy to go into the reaction with.* (Tice)
Warrant: *Which affects the bonds they're related with, they can either broken or formed because they're all somewhat dependent on temperature.* (Reed)

[55:51 – 57:08]
WCD 9/22/2010 ChemActivity T5: Temperature Dependence of the Enthalpy of Reaction, FQ
Claim: Enthalpy change for evaporation of water will not be the same at different temperatures. (Class)
Data: Different heat capacities. (Caprice)
Warrant: *They have different heat capacities. So when we look at the changes, they're not going to vary by the same amount.* (Dr. Black)

[1:04:57 – 1:05:40]
WCD 9/22/2010 ChemActivity T5: Temperature Dependence of the Enthalpy of Reaction, CTQ1
Claim: ΔH [for changing temp of products] is non-zero. (Dominique)
Data: ΔH = CpdT. Because your Cp for your integral for some substances is going to have different values. (Dominique)

Warrant: So this [ΔH] has to be non-0. Because we don't have 0 heat capacities. (Dr. Black)

Whole Class Discussion Argumentation Log for 9/27/2010

[5:01 – 6:29]
WCD 9/27/2010 ChemActivity T6: Entropy, FQ
Claim: The statement (When a hot brick is dropped into cold water, the temperature of the brick must decrease to be consistent with the first law of thermodynamics.) follows the 1st law of thermo. (Tice)
Data: The first law of thermodynamics - conservation of energy. (Tice)
Warrant 1: *Because energy is going to be transferred from the brick to the water.* (Tice)
Warrant 2: *That if the brick must decrease temperature in the water will have to increase in regard to 1st law of thermodynamics*. (Summer)
Alternate Claim: The statement (When a hot brick is dropped into cold water, the temperature of the brick must decrease to be consistent with the first law of thermodynamics.) does not follow the 1st law of thermo. (Genevieve)
Alternate Data: The first law of thermodynamics
Alternate Warrant: *Because the energy can be transferred in different ways other than heat*. (Genevieve)
Rebuttal: *Okay, but in this case though, I think we're pretty much talking about heat exchange*. (Dr. Black)
Alternate Warrant 2: *Because the 1st law of thermodynamics didn't say which way the heat needed to be transferred, it just said that it has to be conserved*. (Jamal)

[7:16 – 8:10]
WCD 9/27/2010 ChemActivity T6: Entropy, FQ
Claim: If you drop a hot brick into cold water it's going to decrease, but it doesn't have to, to be consistent with the 1st law. (Jerome)
Data: First Law of Thermo (Jerome)
Warrant: *The 1st law just says energy is conserved, it doesn't say what happens to it.* (Jerome)
Warrant 2: *The brick is going to get colder, but it doesn't have to, within the confines of that law.* (Jerome)
Backing: The brick could get hotter and the water could get colder according to the first law. (Dr. Black/Class)

[12:53 – 14:32]
WCD 9/27/2010 ChemActivity T6: Entropy, Model 1
Claim: 1-Pentene has more entropy than cyclopentene. (Aiden)
Data: 1-Pentene you can move more. (Aiden)
Data: 1-Pentene has more conformations, cyclopentene is fairly constrained. (Dr. Black)

Warrant: So you're looking at how constrained a system is, more conformations, equals lots more ways I can distribute the energy. (Dr. Black)
Backing: *So when we look at entropy changes for processes, you're looking at whether you're adding or removing constraints.* (Dr. Black)

[14:32 – 15:09]
WCD 9/27/2010 ChemActivity T6: Entropy, Model 1
Claim: If you go from a solid to a liquid you are removing constraints. (Quentin)
Data: Liquid is more free flowing. (Quentin)
Warrant: So there would be more conformations than a solid. (Quentin)

[15:17 – 15:48]
WCD 9/27/2010 ChemActivity T6: Entropy, Model 1
Claim: The gas phase has the highest entropy, the solid phase has the lowest entropy. (Caprice)
Data: Definitions of the three phases. (implicit)
Warrant: *When we look at the complexity of molecules, you're going to look at the available conformations*. (Dr. Black)

[15:48 – 16:14]
WCD 9/27/2010 ChemActivity T6: Entropy, Model 1
Claim: Argon will have higher entropy than helium. (Caprice/Aiden)
Data: Because it's bigger. (Caprice)
Data: More polarized. (Aiden/Caprice)
Data: More electrons. (Aiden/Caprice)
Warrant: *More electrons, so you have more ways you can distribute energy if you have more electrons.* (Dr. Black)

[16:14 – 17:05]
WCD 9/27/2010 ChemActivity T6: Entropy, Model 1
Claim: ΔS universe is normally going to be positive. (Reed)
Data: Second Law of Thermodynamics (POGIL Materials)
Warrant 1: S increases. (Reed)
Warrant 2: *Because if process happens spontaneously, it's got to increase. So typically increase, we think of as being positive*. (Dr. Black)
Backing: ΔS *universe for the 2nd law. So it's the combination of* ΔS *system and* ΔS *surroundings. The other way that we can write the 2nd law is that* ΔS *universe has to be greater than or equal to 0 for something to happen. If the greater than is true, then it happens spontaneously and irreversibly. If the equal sign is true, then it's happening irreversibly in equilibrium*. (Dr. Black)

[28:49 – 29:01]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 2a
Claim: ΔS total would be positive. (Jamal)
Data: $(S_{tot})_{final} > (S_{tot})_{initial}$ (POGIL Materials)

Warrant: S total final minus S total initial is going to be a positive number. (Jamal)

[29:08]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 2b
Claim: Yes, the process is spontaneous. (Jamal)
Data: $(S_{tot})_{final} > (S_{tot})_{initial}$ (POGIL Materials)
Warrant: *That was part of the definition of spontaneous.* (Jamal)

[29:17]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 3a
Claim: ΔS total is negative. (Caprice)
Data: $(S_{tot})_{final} < (S_{tot})_{initial}$ (POGIL Materials)
Warrant: Because if the initial is based on the final, then it's going to give us a number change to negative. (Caprice)

[29:17]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 3b
Claim: No, the process is not spontaneous. (Caprice)
Data: $(S_{tot})_{final} < (S_{tot})_{initial}$ (POGIL Materials)
Warrant: Because of the definition of spontaneous. (Caprice)

[29:41]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 3c
Claim: Yes the reverse process is spontaneous. (Caprice)
Data: $(S_{tot})_{final} < (S_{tot})_{initial}$ (POGIL Materials)
Warrant: *Because the 1st process is not the 1st estimate.* (Caprice)

[29:55]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 4a
Claim: *The sign will either be positive or not have a sign.* (Genevieve)
Data: $(S_{tot})_{final} = (S_{tot})_{initial}$ (POGIL Materials)
Warrant: *It will follow the same rules as S universe*. (Genevieve)

[29:55]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 4b
Claim: The process will not be spontaneous. (Genevieve)
Data: $(S_{tot})_{final} = (S_{tot})_{initial}$ (POGIL Materials)
Warrant: *Spontaneous because if it's 0, it's not spontaneous*. (Genevieve)

[29:55]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 4c
Claim: the reverse process will not be spontaneous. (Genevieve)
Data: $(S_{tot})_{final} = (S_{tot})_{initial}$ (POGIL Materials)

[29:55]

WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 4d
Claim: Yes, the process is at equilibrium (Genevieve)
Data: $(S_{tot})_{final} = (S_{tot})_{initial}$ (POGIL Materials)

[43:01 – 44:36]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 6a
Claim: *The system was the brick and the water was the surroundings, and we did adiabatic enclosure, so whatever the water was (inaud).* (Summer)
Data: A hot brick is tossed into cold water in an adiabatic enclosure. (POGIL Materials)
Warrant: *Because we thought about the water not being adiabatic.* (Summer)
Alternate Claim: System to be the brick and the water (Genevieve Group)
Alternate Data: A hot brick is tossed into cold water in an adiabatic enclosure. (POGIL Materials)
Alternate Warrant: *It's the only thing that had some change in the heat and the temperature, was changing.* (Genevieve)
Rebuttal: *I had a different answer than they did.* (Aiden)
Alternate Claim: The system to be the brick and the surroundings to be the water. (Jamal Group)
Alternate Data: A hot brick is tossed into cold water in an adiabatic enclosure. (POGIL Materials)
Alternate Warrant: *The brick is just a nice little solid equation, and the surroundings would be the water because they're surrounding the brick. And it would not include the rest of the universe because it's an adiabatic system, so it's only taking up the brick and the water.* (Jamal)
Alternate Warrant 2: Because it's excluded from the whole universe. (Caprice)

[45:11 – 45:27]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 6b
Claim: The brick should decrease in temperature, and the water should increase, and they should equilibrate. (Summer)
Data: past experience (Summer)

[45:33 – 45:46]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 6c
Claim: CTQ 6b (A hot brick is tossed into cold water in an adiabatic enclosure. The temperature of the brick will decrease and the water will increase) is not an application of the 1st law (Rosalind)
Data: 1st law of thermo,
Warrant: *Because there's no direction of change implied by the 1st law.* (Rosalind)

[45:48 – 45:53]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 6d
Claim: ΔU total for the process is zero. (Callum)
Data: Energy is conserved. (Callum)

Warrant: *Since our system was the brick and the water, there's not energy being put into it, since adiabatic, there's no energy lost by the system*. (Callum)

[46:07 – 46:10]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 6e
Claim: CTQ 6d (A hot brick is tossed into cold water in an adiabatic enclosure. ΔU total for the process is zero.) is an application of the 1st law (Callum)
Data: 1st law of thermo
Warrant: The 1st law says energy has to be conserved (Callum)

[46:28 – 46:56]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 6d
Claim: $\Delta U_{total} = 0$ (Jamal)
Data: The system and the universe were equal, (Caprice)
Warrant: *Any energy loss from the (inaud) is going to be*. (Reed)
Warrant: *Basically what I was thinking was the loss from the brick was the gain for the water* (Caprice)

[47:08 – 47:15]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 6e
Claim: CTQ 6d (A hot brick is tossed into cold water in an adiabatic enclosure. ΔU total for the process is zero.) is an application of the 1st law. (Caprice)
Data: 1st law of thermo
Warrant: Because it's conserved and it shows the direction. (Caprice)

[47:13 – 49:56]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 6f
Claim: The magnitude for $\Delta S_{total} > 0$. (Jamal)
Data: *Energy is moving from a solid to a liquid, from the brick to the water.* (Jamal)
Rebuttal to Data: we don't have a phase change, the brick didn't change phases (Dr. Black)
Data: *It's a greater distribution of heat though, from the compact brick to a larger system overall*. (Aiden)
Alternate Claim: ΔS_{total} is positive. (Summer Group)
Alternate Data: Because the distribution of energy. (Summer)
Alternate Claim: ΔS_{total} is positive. (Callum)
Alternate Data: Because it's spontaneous (Callum)
Alternate Warrant: *Yeah, the change has to be spontaneous, ΔS system has to be spontaneous, so then the total has to be spontaneous*. (Tice)
Clarifier: So the total can't be spontaneous, the process can be spontaneous, but the math can't be spontaneous. (Dr. Black)
Alternate Claim: ΔS is positive (Jamal)
Alternate Data: *The temperature is going to change between, the heat from the brick is going to go into the wate.r* (Jamal)

Alternate Warrant: *So there's going to be an energy transfer from the brick to the water. And because that energy is going into a system that has more distribution.* (Jamal)
Clarifier: *So you're saying that the entropy of the water is increasing more than the entropy of the brick is decreasing*. (Dr. Black)
Alternate Claim: $\Delta S_{total} = 0$. (Genevieve)
Alternate Data: *Because the process is in equilibrium, and all of the energy is conserved*. (Genevieve)
Rebuttal: But the process doesn't occur in equilibrium and the process is not in equilibrium when you have a hot brick in cold water. (Dr. Black)
Warrant to Rebuttal: *You have to think about the process, not the final state, so where it was at the beginning, where it was at the end*. (Dr. Black)
Claim: ΔS total has to be greater than 0. (Dr. Black)
Data: The process happens spontaneously. (Dr. Black)

[50:28 – 51:35]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 7
Claim: Equilibrium processes are reversible. (Caprice)
Data: That it accounts for, the rate at which it's increasing is the rate at which. The rate at which the reaction. (Caprice)
Clarifier: *You're talking about a reaction at equilibrium, we're talking about processes that go beyond just reactions*. (Dr. Black)
Claim: *Reversible process is at equilibrium, is always in equilibrium (inaud)*. (Reed)
Warrant: *So it will be true that ΔS universe is going to equal 0, but when we think about reversible processes, the processes that occur at, while the system is always at equilibrium.* (Dr. Black)

[57:09 – 57:24]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 11a
Claim: ΔS total for reversible process at constant temperature and pressure is equal to zero (Jerome)
Data: Because it was at equilibrium (Jerome)
Warrant: So it's always the delta, the change between the system and the surroundings is always going to be equal to 0. (Jerome)

[58:07 – 58:24]
WCD 9/27/2010 ChemActivity T6: Entropy, CTQ 11b
Claim: For an irreversible process $\Delta S_{total} = 0$. (Caprice)
Data: *It's irreversible and it happens, then it's spontaneous* (Dr. Black)
Rebuttal: *That has to be greater than 0, doesn't it*? (Jerome)
Rebuttal Data: 2nd Law of Thermo [implied] (Jerome)
Qualifier: *Well, technically that happens, so this is one of those funny things that, if we made it happen, somehow or other, the ΔS total of the universe has to be greater than 0. So if I make a nonspontaneous process happen, when I look at the whole global scheme of things, I've ended up with $\Delta S > 0$* (Dr. Black)

[1:03:52]
WCD 9/27/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, FQ
Claim: The difference in entropy of a gaseous and liquid water decreases as temperature increases. (Aiden)
Data: $\Delta S = q_{rev}/T$ [implied]
Data: *It requires a higher specific heat, a change in it, it would change its* ΔS *less than it will for gas* (Reed)
Warrant: *The same temperature change in the gas will make the temperature increase, which would have a greater effect on your gas*. (Reed)
Alternate Claim: *that at a higher temperature, your reaction, or your phase change is more spontaneous,* (Liam)
Alternate Data: *Because you know that more liquid goes to gas at a higher temperature than at a lower temperature*. (Liam)
Alternate Claim: The difference in entropy of a gaseous and liquid water increases as temperature increases. (Genevieve)
Alternate Data: *Because the* ΔS *of the gas is going to be greater than the* ΔS *of the liquid.* (Genevieve)
Clarifier: *Okay, so you're saying the entropy of the gas increases more than the entropy of the liquid?* (Dr. Black)

Whole Class Discussion Argumentation Log for 9/29/2010

[18:32 – 19:34]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 9b
Claim: Yes, dH_{surr} and dq_{surr} are exact differentials. (Jamal)
Data: $dH_{surr} = dq_{surr}$ (Jamal)
Data Qualifier: Under constant pressure and temperature. (Jamal/Dr. Black)
Warrant: Therefore dq_{surr} is an exact differential. (Jamal)

[19:34]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 9c
Claim: $\Delta S_{surr} = \Delta H/T$ (Jamal)
Data: $dS = dq_{rev}/T$. T is constant, (Jamal)
Warrant: *And you pull that out and integrate so and integral of ds = 1/T integral and dq. That gives you* ΔS *is equal to 1/dq. And if dh is equal to q at constant pressure and temperature, then* ΔS *is equal to 1/T* ΔH. (Jamal)

[22:59]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 10a
Claim: $\Delta S_{tot} = \Delta S_{sys} + \Delta H_{surr}/T$ (Caprice on board)
Data: $\Delta S_{surr} = \Delta H/T$ (POGIL Materials, Answer to CTQ 9c)

Data: $\Delta S_{total} = \Delta S_{system} + \Delta S_{surroundings}$ (Caprice)
Warrant: Do a substitution for ΔS_{surr}. (Caprice)

[22:59]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 10b
Claim: Whenever ΔH goes to 0, ΔH_{surr} and ΔH_{sys} equal, but opposite in sign (Caprice)
Data: ΔH gives us ΔS system plus surrounding. (Caprice)

[24:14 - 27:54]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 10c
Claim: $\Delta S_{total} = \Delta S_{system} - \Delta H_{system}/T$. (Aiden)
Data: *Have ΔS system, so at equilibrium $\Delta S = 0$.* (Aiden)
Warrant: *So when this = 0, ΔS system is going to equal ΔS surrounding but the negative sign. So ΔS surrounding is ΔS over T, and it is going to have a negative sign. So ΔS total, if we substitute this value in this equation. We've going to get ΔS system. Then we substitute (inaud) is negative $\Delta S/T$ here.* (Aiden)
Rebuttal: *So that's true at equilibrium*? (Dr. Black)
Claim: At equilibrium, this is true. So that will (shows something on board) (Aiden)
Rebuttal: You still haven't explained how you go from 10a to 10b (Dr. Black)
Rebuttal Claim: *You guys say that $\Delta H_{surroundings}$ at equilibrium equals - ΔH_{system}* (Quentin)
Rebuttal Data: *So can't you just substitute that in for your surroundings in the first place*? (Quentin)
Rebuttal Warrant: *And then that's where you get your negative? And that's assuming that your constants are temperature and pressure.* (Quentin)

[30:07 – 31:10]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 10c
Claim: The relationship between ΔH_{surr} and ΔH_{sys} is equal and opposite at equilibrium (Caprice)
Rebuttal Claim: That is true at constant temp and pressure. (Dr. Black/Reed)
Rebuttal Data: *Because ΔH is equal to, heat has to be conserved* (Dr. Black)
Rebuttal Data: 1st Law of Thermodynamics
Rebuttal Warrant: Heat in equals Heat out always according to 1st law (Caprice/Quentin)
Rebuttal Backing: *I can convert heat into something else, but if I'm going to heat, heat is transferred energy, and if I'm looking at transferred energy, if I transferred it as heat, the heat lost by one has to equal the heat lost by something else. So heat in has to equal heat out, if I'm doing a transfer of energy as heat. So it's true, you can convert heat energy into work or something else, but I'm doing, just looking at the transfer of energy as heat, then it's got to be the same number.* (Dr. Black)

[32:48]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 12a
Claim: dU = TdS - PexdV (POGIL Materials)
Data: dS = dqrev/T, q = U - w, dq = dU -(-PdV) = dU+PdV (Genevieve)

Data: We know that energy equals heat plus work, so that's our basis equation for this and they give you they give you dS = dq/T for a reversible process. (Genevieve)
Warrant: You can solve for dq, then you can substitute that in for dq (dS = dU + PdV/T). Multiply both sides by T. Solve for dU. (Genevieve)

[33:39 – 35:15]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 12a
Claim: dS = dU/T + P_{ex} dV/T (POGIL Materials)
Data: dS = dq/T for a reversible process, energy = heat + work (Genevieve)
Warrant: *Just do algebraic manipulation first. Just find out what ds is equal to, you just start moving things around. You can add the p external dv term on the du side. So you can add PdV to both sides then divide by T.* (Francis)

[35:52 – 37:47]
WCD 9/29/2010 ChemActivity T6: Entropy, CTQ 12b
Claim: If the temperature of an ideal gas is increased reversibly under conditions of external pressure the entropy change is negative. (Genevieve)
Data: *Looking at is s compared to T.* (Genevieve)
Warrant: *They are indirectly proportional. So as t increases, s is going to decrease. And you're looking at the change of s, so which equals S2 minus S1. And if this value is going to be larger than this value, you're going to have a negative change of entropy*. (Genevieve)
Qualifier: You've made the assumption that the pressure is constant and it's a reversible process. (Genevieve)
Qualifier: *You're assuming that they weren't temperature-dependent either?* (Dr. Black)
Rebuttal: Is that a valid assumption? (Dr. Black)
Claim: The volume is going to be temperature-dependent. (Brain)
Rebuttal: What about the internal energy in the gas, does it depend on temperature? (Dr. Black)
Claim: Yes the internal energy depends on T (Caprice)
Data: Because it's a gas. (Caprice)
Warrant: *So basically you're not going to really know for sure, you just going to know they're indirectly proportional*? (Genevieve)

[42:24]
WCD 9/29/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 1
Claim: dU = TdS - PdV (POGIL Materials)
Data: 1st law, dw = - PdV, dq = TdS
Warrant: *It was pretty much just algebra, plug it in. You get your dq from this equation, do a little algebra, get pressure at ds, then dq is -PV*, (Rosalind)

[43:23 – 43:50]
WCD 9/29/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 3

Claim: dU = TdS - PdV is applicable for all processes. (Dr. Black)
Data: Because it's a state function. Because it's path independent. (Caprice/Kayden)

[45:03 - 48:00]
WCD 9/29/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 4
Claim: $dS = C_v/T\ dT + R/V\ dV$
Data: $dU = C_v dT = TdS - PdV$
Warrant: so substitute in Cvdt for U. add PV down here to that side. And divide by T. Flip it around, Well, we want volume and temperature, so I need to get rid of Pressure. Replace pressure with its definition. nRT divided by v. So I've got nRT over v times 1 over TdV, T's cancel out. Actually, we did molar volume, we don't need the n.

[54:09]
WCD 9/29/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 5
Claim: the total differential is $dS = \partial S/\partial T)_V dT + \partial S/\partial V)_T dV$ (board)
Data: S = S(T,V) (POGIL Materials)
Warrant: *We took the partial derivative of s, in one scenario in respect to t, the other one in respect to v, and all the v. What we did in respect to t, we held v constant, and that would be ds. Ds, with respect to dv, we kept temperature constant. (Caprice)*

[55:20 – 56:07]
WCD 9/29/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 6
Claim: The derivative are: $\partial S/\partial T)_V = Cv/T$ and $\partial S/\partial V)_T = P/T$ (board)
Data: ????
Warrant: *When volume's held constant, in the equation we had before, the 2nd half of it would be 0, just leaving you with the 1st half, down there. And on the top, when volume is held constant, in the equation from before, where is it? When temperature is held constant, sorry, then the 1st half of the equation goes to 0, and you're just left with the rest of the equation.* (Rosalind)
Rebuttal: *Okay, but I don't know how you got what dSdT is equal to? Where's the RdV come from?* (Dr. Black)
Response: *Your dS = Cv/T dT + r over dR x dV.* (Jerome)

[1:00 – 1:53]
WCD 9/29/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 7
Claim: dS = CpdT over T - nRdP over T (Callum)
Data: 1st law, dH = dU + dp + VdP, dU = dq – PdV, dH = CpdT.
Warrant: *Substitute in for du. And that gives us dH = dq - PdV + PdV, which cancels out, + dV_P. So we have dH = dq + PdV, and we know that dS = dq over t, so we just rearrange that, substitute in for dq, which gives us dH = dS, T +, x dS +*

> *dV_P. Substitute in for dH, bringing us this equation. We rearrange that to solve for dS. Okay, so we rearrange that to get dS = CpdT over T - VdP over t. And then we just substituted in for v, which is nRT over p, and then cancel that* (Callum)

[1:04:33 – 1:05:27]
WCD 9/29/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 8b
Claim: The expression in CTQ 8a $(\partial S/\partial T)_P$) is applicable for ideal gases. (Rosalind)
Data: Because the expression for dS in CTQ 7 was calculated as ideal (Rosalind)
Rebuttal: So the part that depended on being ideal gas was that 2nd term. Is that 2nd term still there? (Dr. Black)
Claim: So the expression doesn't have to be for an ideal gas. (Rosalind)
Qualifier: But it does have to have constant pressure (Male/Rosalind)

[1:14:44 – 1:15:46]
WCD 9/29/2010 ChemActivity T7: Entropy Changes as a Function of Temperature, CTQ 11
Claim: The change in entropy of the reaction gets bigger. (Male)
Data: Constant pressure process in which $\Delta_r Cp$ is greater than zero, and doesn't depend on temperature. The temperature increases. (POGIL Materials)
Warrant: You're increasing your final, then you're going to receive a bigger number (inaud) (math of logs). (Male)

Whole Class Discussion Argumentation Log for 10/4/2010

[01:00:19 – 01:00:50]
WCD 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 2
Claim: As temperature increases, entropy increases. (Summer/Thaddeus)
Data: No molecular movement. (Summer/Thaddeus)

[01:05:33]
WCD 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 3
Claim: S = 0 means no movement. (Callum)
Data: Temperature is 0K (3^{rd} law). (Callum)
Warrant: Can't have less than no movement. (Callum)

[01:05:56 – 01:06:20]
WCD 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 3
Claim: Phase change gives dramatic change in entropy (Dr. Black)
Data: Graph on page 108 (POGIL Materials)
Warrant: Because there is an increase in movement. (Jerome)

Backing: Move movement means more ways to distribute energy, it's not just particle movement. (Dr. Black)

[01:06:06 - 01:06:43]
WCD 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 4
Claim: There is a transition in the solid region. (Dr. Black)
Data: Graph on page 108 (POGIL Materials)
Warrant: There are different energy transitions taking place? (Jerome)

[01:08:16]
WCD 10/4/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 4
Claim: Within solid region, you begin to activate vibrational modes. (Dr. Black)
Data: At low temperature. (Dr. Black)
Warrant: You have to increase temperature too access those upper (vibrational and rotational) modes (Dr. Black)

Whole Class Discussion Argumentation Log for 10/6/2010

[03:03 – 7:28]
WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 8
Claim: ΔS= Cp logT (board)
Data: At 0K, entropy = 0 (POGIL Materials)
Data: Model 3, page 109 (POGIL Material)
Data: $S_{125}=S_0 + \int_{125}^{0} \frac{CpH2O(s)}{T}$ (Jahara)
Warrant: Do the integration. (Jahara)
Rebuttal: Cannot pull Cp out as a constant during integration. (Jerome)
Data: Cp is temperature dependent (Jerome)
Warrant: It's as a function of temperature that it could vary with temperature in that sense, and you couldn't just pull it out of the integral either. (Jerome)
Response: Must do product rule (Jahara) (This is Jahara's response to Jerome Rebuttal Argument, this seems to be how he thinks the problem should be done.)
Rebuttal: But you are trying to find entropy. (Dr. Black)
Claim: Change in temperature is 125. (Jahara)
Rebuttal: You are trying to find change in entropy at 125. (Dr. Black)
Claim: Relative to absolute 0, ΔS=S (Jahara)
Data: Model 3, page 109 ($S^{\circ}_{T_2} - S^{\circ}_{T_1} = \int_{T_1}^{T_2} \bar{C}_p \frac{dT}{T}$) (POGIL Material)
Warrant: Replace T1 and T2 with actual T. Integrate from 0-125 (Dr. Black)
Qualifier: So Cp is constant with temperature? (Maroon)
Backing: Leave Cp in integral (Dr. Black)

[07:43- 8:38]
WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 8

Claim: We are assuming this is a perfect crystal. (Jahara)
Data: 3rd law of thermodynamics
Warrant: To assume zero entropy at 0K, it must be a crystal. (Jerome/Dr. Black)
Backing: Unless you have a perfect crystal you always have a little bit of residual entropy. (Dr. Black)

[10:08 - 10:43]
WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 8
Claim: General Expression: $S_{125}(H_2O) = S_0 + \int_0^{125} \frac{CpH2O(s)}{T}$ dT (Dr. Black/board)
Data: Third Law, Model 3 Equations, page 109 (POGIL Materials)
Warrant: *So in this case you are basically changing the energies at the zero point energy and you kept the Cp in so you would integrate it.* (Male)

[11:10 - 11:55]
WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 9a
Claim: S273= $\int_{273}^{0} \frac{CpH2O}{T}$ (Jerome)
Data: T = 273, Entropy = 0 @ 0K (POGIL Materials)
Warrant: 273.15*Cp=0 or T1 at 0 K (Jerome)
Backing: Cp doesn't change with the function. (Jerome)

[13:35 - 15:01]
WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 9b
Claim: $SH_2O(l) > SH_2O(s)$ (Male)
Data: Water is less structured. (Male)
Warrant: Liquid has more states available to more space. (Male)
Backing: *... its a liquid, it has mixed position, it has more states available and that's how we define entropy the number of distribution of entropy over available states.* (Dr. Black)

[16:47 - 18:24]
WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 9c
Claim: $S_{H2O} = \int_0^{273} \frac{Cp}{T} dT$ + ΔH/T (board)
Data: H_2O at 273K and 1 bar (POGIL Materials)
Rebuttal: Would it be ΔH/T, wouldnt it just be ΔH fusion at standard state because it's right at 0° Celsius. (Jerome)
Clarifier: How do you determine ΔH? (Dr. Black)
Response: ΔH has a little dot (Male)
Claim: Need to keep it as ΔH/T (Tice)
Data: Entropy = ΔH/T (Tice)
Rebuttal: *It doesn't equal H over T, What our basic definition that we use for entropy, not our definition but our basic equation that we tend to use.* (Dr. Black)
Response Claim: $dS = dq_{rev}/T$ (Thaddeus)

[24:28 - 25:44]

WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, General Discussion

Claim: For $H_2O(l) \rightarrow H_2O(s)$ @ 10 degrees C, heat water to 0, phase change, cool solid (Dr. Black/students)

Data: Phase Change Diagrams and equations.

Warrant: You have to have a reversible process (Dr. Black/group)

[36:57 - 37:38]

WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 11

Claim: The entropies in Table 1, page 111 are positive. (POGIL Materials)

Data: Table 1, page 111 (POGIL Materials)

Warrant 1: It's under standard conditions. (group 1 board)

Warrant 2: All entropies are positive relative to zero has no units/third law. (group 2 board)

Warrant 3: Absolute entropy. (group 3 board)

Backing 3: *The definition that energy is the distribution of energy among states you can have. So negative entropy can be when calculating it but if absolute zero is the measurement of energy among states then you can't go to anything below that.* (group 3)

[39:00 - 39:41]

WCD 10/6/2010 ChemActivity T8: The Third Law of Thermodynamics, CTQ 12a

Claim: $\Delta_r S$ is positive. (boards)

Data: $KClO_4(s) = KCl(s) + 2\ O_2(g)$ (POGIL Materials)

Data: Table 1, page 111 (POGIL Materials)

Warrant: You are going to have a phase change going on to gas, and also you are going from one mole of reactant to three moles of product. (Kayden)

[49:29 - 49:58]

WCD 10/6/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, FQ

Claim: Reaction will not go. (Liam)

Data: More moles of reactant, less moles of product (entropy decreases). (Liam)

Warrant: Spontaneity determined by entropy to determine direction (reaction won't go towards a lower entropy). (Liam)

[50:14]

WCD 10/6/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, FQ

Claim: Reaction does occur. (Brian)

Data: Sum of products bond strengths is larger than reactants, number of moles reactant decreases. (POGIL Materials)

Warrant: *So the combustion of hydrogen forms water so you have 1.5 moles to every mole of product and we know that ΔH for that is negative release of energy and we know that reaction does occurs so we know that's ΔS is positive.* (Brian)

[50:47]

WCD 10/6/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, FQ
Claim: Maybe the reaction will occur. (Jerome)
Data: Sum of products bond strengths is larger than reactants, number of moles reactant decreases. (POGIL Materials)
Warrant: *We argued if your bond strength gains, or if your change, if it's energetically favorable enough, your product, your bond strength gains, then it will outweigh any uh, entropy losses so it could still happen.* (Jerome)

[51:09 - 53:10]
WCD 10/6/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, FQ
Claim: The reaction will not occur. (2 groups)
Data: Sum of products bond strengths is larger than reactants, number of moles reactant decreases. (POGIL Materials)
Data: Entropy of the system is negative (2 groups). (entropy won't increase because there are fewer moles and greater bond strength)
Warrant: Reaction will not occur is entropy of the system is negative. (Dr. Black/Caprice)
Rebuttal Claim: Only entropy of the universe determines spontaneity (Dr. Black/Kayden)
Qualifier: Gibbs energy is necessary to consider the perspective of the system (Dr. Black)
Rebuttal Data: $\Delta H < 0$, $\Delta S < 0$ (Dr. Black)
Rebuttal Warrant: One favors reaction, the other disfavors. (Dr. Black/Kayden)
Rebuttal Backing: Must consider magnitudes. There is not enough information to determine if the reaction will go or not (Dr. Black)

[1:07:23 - 1:07:55]
WCD 10/6/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 3
Claim: Can determine spontaneity by looking at values related to the system (Dr. Black)
Data: $dw \geq dU - TdS$ (POGIL Materials)
Warrant: Must generalize equations to include measurables (Dr. Black)

Whole Class Discussion Argumentation Log for 10/13/2010

[00:01 - 02:42]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 4a
Claim: $dA = dU - TdS$ (Elliot)
Data: $A = U - TS$ (POGIL Materials)
Warrant: Apply state function to data. (Elliot)
Rebuttal: Why did T come out? Did you chain rule? (Student)
Resolved Claim: $dA = dU - TdS - SdT$ (Ron, Elliot, Caprice)
Data: $dA = dU - d(TS)$ (Caprice)
Warrant: Use the chain rule (Ron)

[02:46 - 03:09]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 4b

Claim: dA = dU - TdS (Elliot)
Data: dA = dU – TdS - SdT (Q4a)
Warrant: At constant temperature, last term is zero. (Elliot)

[03:11- 11:29]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 4c
Claim: At constant temperature, d(U-TS) $\leq$ w (Elliot)
Data: dU = dq +dw, 1st law of thermo. (implicit)
Warrant: Incorporate entropy. (Elliot)
Rebuttal: More efficient way if you incorporate your answer from CTQ 3. (Dr. Black)
Alternative Claim: dA = dw (Brian)
Alternate Data: dA = dU - TdS, dS = dq/T (POGIL Materials, Answer CTQ 4b, Thaddeus)
Alternate Warrant: Substitute the definition of dS for the dS in dA = dU - TdS, cancel out temperature, substitute first law of thermodynamics, cancel out dq (Brian)
Rebuttal: How do we know dS = dq/T (Aiden)
Response: dS = dq/T for a reversible process. For irreversible process, dS $\geq$ dq/T (Dr. Black/Aiden)
Alternative Claim: dw $\geq$ dA (Aiden)
Alternate Data: dS = dq/T, U = q + w dA = dU – TdS (POGIL Materials, Answer CTQ 3)
Alternate Warrant: Use first law to substitute in for dq, multiply both sides by T, use definition of dA to simplify right side of inequality. (Aiden)
Rebuttal: There is one not so true statement. (Dr. Black)
Response: dU = dq – dw (Aiden/Caprice)

[15:11 - 15:58]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 5
Claim: dA < 0 (Thaddeus)
Data: A = U - TS, dA = dw (Problem CTQ 5/Dr. Black)
Warrant: Since no work was done, you would always have a value –TdS. (Thaddeus)
Backing: If there is no change in volume, work equals zero and it is spontaneous. (Dr. Black/Male)

[16:00 - 18:23]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 6
Claim: Helmholtz energy is useful for determining if a reaction is spontaneous. (Dr. Black/class)
Data: dS = dq/T for reversible reaction, dS > dq/T for spontaneous and irreversible reaction (Dr. Black/Class)
Warrant: If substituting dS, dA = dw for reversible equilibrium process (Dr. Black/Class)
Backing: For constant V (no work), dA = 0 for a reversible process and dA < 0 for an irreversible process (Dr. Black/Class)

[20:21]

WCD 10/6/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 7b
Claim: G = U – TS + PV (Thaddeus/POGIL Materials)
Data: G = A + PV, A = U - TS (solutions to previous problems)
Warrant: Substitute A = U - TS for A in G = A + PV (Thaddeus)

[23:26]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 7c
Claim: G = H - TS (Francis/POGIL Materials)
Data: H = U + PV (Francis/board)
Warrant: pull out a U and A + PV, end up with G = H(-TS).

[24:30 - 25: 29]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 7d
Claim: $\Delta G = \Delta H - T\Delta S$ (Class)
Data: dG = dH – TdS - SdT (Brain/board)
Warrant: At constant temperature, last term cancels out. The rest of the terms are state functions, so can be considered as deltas. (Dr. Black/Class)
Rebuttal Claim: So wouldn't $\Delta G = 0$?(Caprice)
Rebuttal Data: $\Delta H = T\Delta S$ (Caprice)
Rebuttal: Is that true? (Dr. Black)
Resolution: $\Delta G = 0$ for reversible process at equilibrium. (Dr. Black/Caprice)
Data: $\Delta H = T\Delta S$ (Caprice)
Warrant: Data is only true for a reversible process at equilibrium. (Caprice/Male/Dr. Black)

[28:21]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 8
Claim: $\Delta A + P\Delta V \leq w_{nonpv}$ (Dominique)
Data: $w = w_{pv} + w_{nonpv}$ (Dominique)
Warrant: Substitute in A, substitute in $w_{pv} = -P\Delta V$, move to other side of inequality. (Dominique)

[31:25 - 32:16]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 9
Claim: $\Delta G \leq W_{nonpv}$ (board/Aiden)
Data: $\Delta G = \Delta A + P\Delta V$, at constant pressure. (Reed)
Warrant: *This equal, this there, and this equals ΔG, so ΔG is less than non pv work.* (Aiden)

[1:00:25 – 1:02:46]
WCD 10/13/2010 ChemActivity T9: Gibbs Energy and Helmholtz Energy, CTQ 16
Claim: $\Delta S_{total} = \Delta S_{sys} - \Delta H/T$ (Male)
Data: T and P constant, $\Delta G = -T\Delta S_{tot}$ (POGIL Materials)
Data: $\Delta H - TdS = \Delta G$
Warrant: Multiply through by T. (Dr. Black)

Whole Class Discussion Argumentation Log for 10/18/2010

[4:32 - 5:33]

WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, FQ

Claim: If temperature goes up, Gibbs energy goes down. (Caprice)
Data: The equation (G = U + PV - TS) (Rosalind)
Warrant: Because G is proportional to P. (Rosalind)
Backing: It's negative temperature, and it's proportional, so the temperature goes up, it equals. (Patrick)

[10:10 - 14:21]

WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 2

Claim: dG = VdP – SdT (Jerome/Rosalind)
Data: G = U + PV - TS
Warrant: Take the derivative. Substitute dq +dw for dU, substitute PdV for dw, substitute TdS for dq. (Jerome/Rosalind)
Backing: Assuming reversible process allows for the substitutions for dq and dw. (Rosalind)
Rebuttal: *What does reversible process have to do with your work equation?* (Dr. Black)
Response: Also assuming that work in non-pv work (Jerome/Dr. Black)

[29:11-30:00]

WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 3

Claim: dG is generally applicable. (Reed/ Dr. Black)
Data: G is a state function.
Warrant: *Since one of our assumptions is that it's a reversible process, which deals with how you get there, it deals with during the reaction. It doesn't really count for a state function. And I guess also that we usually discount non-pv work.* (Reed)

[30:40 - 32:23]

WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 4b

Claim: $\partial G/\partial P)_T = V$ (Dr. Black/Dominique's group)
Data: dG = VdP - SdT (Dominique)
Warrant: *The partial derivative of G with respect to the partial derivative of p while keeping T constant. It is equal to VdP when it's times the derivative of V. But then when you divide by the derivative of P on both sides, then you just get V =V* (Dominique)
Claim: $\partial G/\partial T)_P = -S$ (Dominique)
Data: dG = VdP - SdT (Dominique)

Warrant: You get that equal to SdT, then divide by the derivative of T. (Dominique)

[32:30 - 33:17]
WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 4b
Claim: $\partial G/\partial P)_T = V$ and $\partial G/\partial T)_P = -S$ (Dr. Black)
Data: dG = VdP - SdT (POGIL Materials)
Warrant: Determine the derivative by inspection. I have dg equals something times dT plus something times dP (Dr. Black)
Warrant 2: *So we can see that dP correlates here, so that this v correlates to that section. And our negative S correlates to that because your dT is right there, it's kind of just matching them up.* (Reed)

[33:28 - 33:50]
WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 4c
Claim: $\partial G/\partial T)_P = (G-H)/T$ (Quentin)
Data: G = H - TS (Quentin)
Warrant: Isolate S and make negative. (Quentin)

[45:43 - 46:00]
WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 6b
Claim: $G - G^\circ = nRT\, ln\frac{P}{P^\circ}$ (Dr. Black/boards)
Data: PV = nRT, dG = VdP - SdT (POGIL Materials)
Warrant: Don't assume that volume is constant, integrate with respect to pressure, And so ideal gas equation lets me have an equation for volume in terms of pressure. (Dr. Black)

[46:55 - 47:10]
WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 6c
Claim: $\mu - \mu^\circ = nRT\, ln\frac{P}{P^\circ}$ (boards)
Data: $G - G^\circ = nRT\, ln\frac{P}{P^\circ}$ (Dr. Black/CTQ6b)
Warrant: divide through by n (Dr. Black)

[56:12 - 1:00:07]
WCD 10/18/2010 ChemActivity T10: Gibbs Energy as a Function of Temperature and Pressure, CTQ 8a
Claim: $\mu_{H2\ pure} < \mu_{H2\ mix}$ (Callum)
Data: Model 3 page 122 (POGIL Materials)
Warrant: *I said that mu is equal to G over n, and you only have 1 N_2, and so on the mixed side you have 2N_2s, and it's inversely proportional, like if n goes up, then mu goes up. (probably meant the mu goes down) So since the mixed side has more N_2.* (Callum)

Warrant: We didn't consider the moles in the N_2, just the moles in the H_2, we assume there's more moles on the pure side of hydrogen than there was on the mixture side, because you had moles of nitrogen taking up space. (Quentin)

Rebuttal: *Why wouldn't it be the same as H_2 moles?* (Male)

Response: *Oh, they're ideal so they don't take up space and have interactions and stuff.* (Quentin)

Backing: *Actually, even if it's a real gas, by and large, if you're talking about gases, and you've done these equations forever, do we even pay any attention to the other gases, or do we treat each one of them like they're the only thing in the container? Because they're so spread apart, even if we're not treating them ideally, accounting for the fact that they have volume. I mean the volume of this might, I have a really tiny high-pressure system, then the volume of the nitrogen might affect what the volume of the container available is. But I've got a reasonable size container, it's not going to come into affect any significant proportion.* (Dr. Black)

Alternate Claim: $\mu_{H2\ pure} = \mu_{H2\ mix}$ (Caprice)

Alternate Data: $\mu = G/n$ (Jerome)

Alternate Warrant: Because they are ideal gases and H_2 is the only permeable gas, they will equilibrate pressure-wise, resulting in equal number of moles on each side (Jerome)

Alternate Warrant 2: *We were assuming that the H_2 and the N_2 were both ideal gases, and that there would be the same moles of hydrogen gas on both sides.* (Jake)

Rebuttal to Warrant 2: *You don't need to assume that. This actually doesn't work if you assume you've got the same, the same total moles on each side*. (Dr. Black)

Alternate Backing: *Equilibrium means that there's no driving force, right? And for no driving force, that means the potential has to be the same, I don't have it tilted either way (gestures), does that make sense?* (Dr. Black)

Whole Class Discussion Argumentation Log for 10/20/2010

[10:49 – 12:15]

WCD 10/20/2010 ChemActivity T11: Equilibrium, FQ

Claim: The pressure would change based on the equilibrium constant. (Jamal)

Data: $PCl_5(g) \leftarrow \rightarrow PCl_3(g) + Cl_2(g)$ (POGIL Materials)

Warrant: *If you form more products, then the number of moles is going to increase, and the pressure is going to increase. Rising toward the reacting side, then the moles are going to decrease, and the pressure is going to decrease.* (Jamal)

Backing: *That makes sense, so they actually looked at what the change is, so that the ratio is equilibrium there. If it's at equilibrium, then there would be no change, if it's less than equilibrium, then it would increase in greater than or equal.* (Dr. Black)

[15:27 - 15:48]

WCD 10/20/2010 ChemActivity T11: Equilibrium, Model 1

Claim: At equilibrium, rate of change in both directions of a reaction are equal. (Dr. Black)

Data: It is a dynamic process with no net change at macroscopic level. (Dr. Black/male)

[23:18 – 24:43]

WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 1

Claim: 1 mole N_2 consumed, 3 moles of H_2 are consumed, 2 moles of NH_3 are produced. (Class)

Data: $N_2(g) + 3\ H_2(g) \leftarrow\rightarrow 2\ NH_3(g)$ (POGIL Materials)

Warrant: *Basically, you multiply that entire reaction by 1*. (Brandy)

Warrant: *So it's saying I have 1 unit of the reaction, so whatever the reaction is, I have 1 unit of that reaction. So that's when you're talking about a mole of reaction, you might even think of it as a unit of reaction, but we're basing it on moles*. (Dr. Black)

Backing: *We have to do things in terms of the reaction, not each individual component. Because you want something that's going to be the same for everything. The rate of change of these different components is going to be different.* (Dr. Black)

[24:43 – 24:55]

WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 1

Claim: Nitrogen and Hydrogen are not being consumed at the same rate. (Caprice/Quentin)

Data: $N_2(g) + 3\ H_2(g) \leftarrow\rightarrow 2\ NH_3(g)$ (POGIL Materials)

Warrant: Hydrogen is consumed 3x as fast as Nitrogen (Dr. Black)

[25:53 - 28:19]

WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 2

Claim: $nN_2 = n_oN_2 - \xi$
$nH_2 = n_oH_2 - 3\xi$
$nNH_3 = n_oNH_3 + 2\xi$ (Class)

Data: $N_2(g) + 3\ H_2(g) \leftarrow\rightarrow 2\ NH_3(g)$ (POGIL Materials)

Warrant: For the signs: Positive is for products, negative is for reactants. The coefficients come from the mole of each molecule in the reaction. (Quentin)

Backing: The coefficients give us the ratio, so we know if we have Xi moles of reaction that means Xi moles of this reactant. (Dr. Black)

[41:03 – 43:19]

WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 3a

Claim: $dnN2/d\xi = -1$
$dnH2/d\xi = -3$
$dnNH3/d\xi = +2$ (Rosalind)

Data: $nN_2 = n_oN_2 - \xi$
$nH_2 = n_oH_2 - 3\xi$
$nNH_3 = n_oNH_3 + 2\xi$ (POGIL Materials, Answer to CTQ 2)

Warrant: For the signs: Positive is for products, negative is
Warrant: We just took what C was, the change, and then divided it by what i was (Ashley)
Rebuttal: What do you mean by 'what i was?' i is N_2, so -i divided by N_2 doesn't make sense (Dr. Black)
Response Warrant: *We just took the given change, of the amount of the reactants for a unit of reaction, the Xi. And then basically equals -1, because it changed from 1 for a negative reaction.* (Jerome)
Alternative Warrant: *we took the derivative of what we found for the equations for n_i. And your n_o for each, the different molecules, that drops out. And you're just left with find the derivative of Xi, which it's not to any power for the, so you're just going to be coefficients* (Dominique)
Alternative Warrant: *Or you could do it by inspection; when I change my amount Xi, this is how much the amount the moles change with respect to that*. (Dr. Black)

[44:32 – 44:56]
WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 3b
Claim: Positive is products, negative is reactants (class)
Data: $nN_2 = n_oN_2 - \xi$
$nH_2 = n_oH_2 - 3\xi$
$nNH_3 = n_oNH_3 + 2\xi$ (POGIL Materials, Answer to CTQ 2)

Warrant: *whenever your change, whenever it's for your reactants negative, that's what you're losing. Whenever it's the products, it's positive, because that's what you're gaining*. (Reed)

[45:14 – 45:49]
WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 3c
Claim: The magnitude of Vi and the component i are directly related. (board)
Data: ?
Warrant: The magnitude of the i is going to be directly related to the magnitude that you have for the number of moles of, for each coefficient, of each. (Quentin)
Rebuttal: So you can actually get more specific and directly related. (Dr. Black)
Claim: *They are the same.* (Quentin)
Clarifier: *Right, 'equal to' is a little bit different than just 'proportional to.' it's more than just proportional, it's actually equal to the magnitude of the coefficient.* (Dr. Black)

[46:14 - 47:13]
WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 3d
Claim: VA = -a, VB = -b, VC = -c (Class)
Data: aA → bB + cC (Dr. Black)

[1:11:26]
WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 6

Claim: Heat of formation for graphite and hydrogen gas are zero. (boards)
Data: Table 1, page 131 (POGIL Materials)
Warrant: Because they are element in their standard states. (boards)

[1:11:46 – 1:12:56]
WCD 10/20/2010 ChemActivity T11: Equilibrium, CTQ 7
Claim: ΔH = 131 KJ/mol (class)
Data: Table 1, page 131 (POGIL Materials)
Warrant: *To get enthalpy of reaction, we took the products minus reactants of each amount of enthalpy. So we're really using carbon monoxide and water in this case. So we take the enthalpy of carbon monoxide, and we subtract that from the -242, get a +31.* (Quentin)
Claim: ΔS = -134 KJ/mol (class)
Data: Table 1, page 131 (POGIL Materials)
Warrant: *it's the same thing, products minus reactants. And so we just took the values from the table.* (Dominique)
Claim: ΔG = 91.1 KJ/mol (class)
Data: Table 1, page 131 (POGIL Materials)
Warrant: *We used the equation, ΔGr naught equals ΔHr naught minus temperature times Δof the reaction S naught. And we converted the 1 joule, or one is in joules per mole, or kilojoules per mole, and then react (inaud).* (Tice)

VITA

VITA

Alena Moon was born in Pullman, Washington on June 29, 1990. She graduated from high school at Annapolis Christian Academy in Corpus Christi, Texas in May 2007. She attended John Brown University in Siloam Springs, Arkansas and graduated with a Bachelor of Science in Chemistry in May 2011. Following her completion of a Ph.D. in Chemistry Education, she will begin a postdoctoral research fellowship with Ginger Schultz and Anne Gere at the University of Michigan. She hopes to pursue a career in faculty and graduate professional development.

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The nature of students' chemical reasoning employed in scientific argumentation in physical chemistry

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Recent science education reform efforts have emphasized scientific practices in addition to scientific knowledge. Less work has been done at the tertiary level to consider students' engagement in scientific practices. In this work, we consider physical chemistry students' engagement in argumentation and construction of causal explanations. Students in two POGIL physical chemistry classrooms were videotaped as they engaged in discourse while solving thermodynamics problems. Videos were transcribed and transcripts were analyzed using the Toulmin Argument Pattern (TAP). Arguments were then characterized using the modes of reasoning in a learning progression on chemical thinking (CTLP) (Sevian and Talanquer, 2014). Results showed that students used primarily relational reasoning, in which no causal explanation is generated, rather a single relationship between variables was used to justify a claim. We discuss all types of reasoning present in students' arguments.

Introduction

Recent science education reform efforts have emphasized explicitly teaching scientific practices in addition to scientific knowledge (NRC, 2012a, 2012b; Cooper *et al.*, 2015). Scientific practices include the means by which scientific knowledge is generated. One of these fundamental scientific practices, argumentation, requires students to make claims based on evidence (Driver *et al.*, 2000; Bell, 2000; Bell, 2004; Garcia-Mila and Andersen, 2007; Berland and Reiser, 2009; NRC, 2012a, 2012b). In addition to modeling authentic scientific discourse, facilitating argumentation in the classroom has also shown to promote learning content knowledge (Zohar and Nemet, 2002; Asterhan and Schwarz, 2007; von Aufschnaiter *et al.*, 2008). To improve students' abilities to engage in building scientific arguments, instructors must explicitly teach argumentation (Berland and Reiser, 2011; Christodoulou and Osborne, 2014). In this study, we aim to consider how physical chemistry students engaged in this scientific practice. To identify and consider arguments, Toulmin's Argument Pattern (TAP) was used to extract arguments constructed in two POGIL physical chemistry classrooms. In order to characterize the reasoning in students' arguments, we use the framework of chemical thinking (Sevian and Talanquer, 2014). Chemical thinking refers to the "development and application of chemical knowledge and practices with the main intent of analyzing, synthesizing, and transforming matter for practical purposes." (Sevian and Talanquer, 2014). Considering the students' reasoning equips us to move past only evaluating students' content knowledge to evaluating their ability to think and argue like a scientist (Berland and Reiser, 2011; Evagorou and Osborne, 2013). Motivated to consider upper-level undergraduate students' participation in the scientific practices of argumentation, this study aimed to answer the following research question:

What is the nature of students' chemical reasoning as evidenced by their argumentation across two different POGIL chemistry classrooms?

To answer this question, a qualitative discourse analysis method was used in which arguments were identified in classroom talk using Toulmin's Argument Pattern (Cole *et al.*, 2012). Rather than exclusively investigating the presence and construction of arguments, we aimed to evaluate the content of the arguments to assess the quality of causal reasoning students were employing.

Background

Argumentation

Argumentation is the practice of generating, considering, and comparing arguments. Arguments are composed of a claim or conclusion supported with evidence (Toulmin, 1958; Garcia-Mila and Andersen, 2007). There has been growing interest in incorporating argumentation into the science classroom

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(Bricker and Bell, 2008), as explicitly teaching and facilitating argumentation invites students to participate in scientific discursive practices, which is highlighted as an objective in science education (Duschl *et al.*, 2007; Kelly, 2008; NRC, 2012a, 2012b). It also serves as an insightful platform for identifying patterns in students' reasoning, as building arguments requires students to articulate causal explanations for phenomena (Berland and Reiser, 2009).

Little work in argumentation has been published at the tertiary level. In chemistry, argumentation has served as a lens for describing reasoning patterns in a POGIL physical chemistry classroom (Becker *et al.*, 2013). Becker *et al.* (2013) found that a sociochemical norm emerged in the classroom in which arguments were justified using particulate-level reasoning. In a separate analysis, Becker and colleagues also found that the instructor served an important role in promoting reasoning across multiple levels (macroscopic, submicroscopic, and symbolic). In comparing the small group and whole class discourse, they found that small group discourse centered largely on the symbolic level, while the whole class discourse, which included more instructor discursive moves, helped elicit reasoning across multiple levels (Becker *et al.*, 2015).

In introductory chemistry, Kulatunga and Lewis (2013) explored students and peer leaders' verbal behaviors in a general chemistry course incorporating peer-led guided inquiry sessions. Researchers compared two small groups to identify differences in frequency of individual arguments *versus* collaboratively constructed arguments and patterns in the individual contributions to collaboratively constructed arguments. Without peer leader intervention, students were largely able to construct arguments with their peers that included evidence and justification. Further, if an argument included an incorrect claim, students corrected it and achieved resolution through argumentation (Kulatunga *et al.*, 2013). By distinguishing between different peer leader verbal behaviors, researchers identified patterns in two peer leaders' interactions with their small groups. The evidence provided in students' arguments largely resulted from short questions, which targeted facts, while the justifications in arguments were frequently generated in response to probing and clarifying questions, which generally take the form of "why" or "how" (Kulatunga and Lewis, 2013).

There are examples of inquiry into university students' argumentation in other disciplines, such as oceanography (Kelly and Takao, 2002; Takao and Kelly, 2003) and engineering (Erduran and Villamanan, 2009). These studies evaluated students' written arguments generated in response to a writing scaffold that included a data set. Kelly and Takao (2002) constructed a rubric that evaluated arguments using epistemic criteria. Epistemic levels were proposed that ranged from one level including references to specific data to another level that included references to general geological principles. These levels were used to characterize students' arguments. Erduran and Villamanan (2009) illustrated the difficulty that tertiary engineering students experienced with using experimental evidence to support their arguments.

With dialogic argumentation in the context of chemistry, the instructor or facilitator plays an important role in eliciting arguments and promoting scientific reasoning. With written argumentation in other disciplines, the task and data set inform the quality of resulting arguments. In both written and dialogic argumentation, support is necessary to help students learn to interpret experimental data, construct coherent arguments drawing on data, and employ reasoning across multiple representational levels. Little work has been done to understand how tertiary students use cause and effect reasoning to construct arguments. This is especially relevant in the context of chemical thermodynamics, which has the potential to answer "why" and "how" many chemical processes occur.

Scientific reasoning

In considering student reasoning, the next generation science standards (NGSS) framework for K-12 science education in the United States identifies crosscutting concepts that span scientific inquiry (NRC, 2012a, 2012b). Of these concepts, the most relevant for this study was building arguments using cause and effect, or mechanisms. Cause and effect descriptions serve to answer the "why" and "how" scientific questions. The framework highlights how cause and effect mechanisms range in complexity depending on the system being investigated. This capacity to generate mechanisms that use cause and effect is also important to explicitly teach at the undergraduate level as research suggests chemistry experts possess this skill (Sevian and Talanquer, 2014).

This study considers the overall scientific reasoning and use of causal models in classroom arguments. Research shows that more expert-like causal models are dynamic, integrated, and complex (Perkins and Grotzer, 2005; Brown *et al.*, 2010). However, the causal models that students or novices generate and draw upon tend to be linear and oversimplified (Grotzer, 2003; Perkins and Grotzer, 2005). Further, novices can focus on single salient features of a problem or phenomenon and assign them total causal agency (Smith *et al.*, 1985; Perkins and Grotzer, 2005; Sevian and Talanquer, 2014). However, explicitly teaching different causal models results in students using more complex models in their explanations (Perkins and Grotzer, 2005).

This body of literature largely focuses on primary and secondary students. Less work has been done with upper level science, technology, engineering, and mathematics (STEM) students to evaluate their scientific reasoning and use of scientific mechanism (Taber and Watts, 2000). Though expectations for chemistry undergraduate students' skills vary across institutions, this lack of research in the post-secondary chemistry classroom is indeed a gap considering that students nearing the end of their degree should ideally possess competencies essential to being a professional chemist (ACS CPT, 2015). In one study, Sevian and Talanquer (2014) interviewed chemists ranging from undergraduate students to chemistry faculty members (representing a novice to expert range) using the GoKart question (Szteinberg *et al.*, 2014). One goal of their work was to elicit the types of reasoning employed by the participants and describe a learning progression for chemical thinking that characterizes qualitatively different levels of reasoning about chemical processes. This learning progression is valuable for characterizing students' reasoning,

specifically students' use of causal reasoning. For this reason, it is used in this study to characterize physical chemistry students' reasoning as evidenced by their arguments. As this progression is grounded in a theoretical commitment to a focus on disciplinary [chemistry] core practices, it serves as a domain-specific measure of argument quality.

Process oriented guided inquiry learning (POGIL) approach

Student reasoning was explored in two classrooms in which the Process-Oriented Guided Inquiry Learning (POGIL) pedagogy was used. POGIL classrooms emphasize the development of process skills through small group discourse, providing an ideal space for considering students' participation in practices of constructing arguments and explanations. Use of the process-oriented guided inquiry learning (POGIL) approach at the undergraduate level has been shown to improve student attitudes (Chase *et al.*, 2013), performance on ACS standardized examinations (Hein, 2012), and grades (Conway, 2014). While the use of POGIL in the classroom has been widely studied, the effect of the POGIL approach on student learning or reasoning at the physical chemistry level has received less attention (Becker *et al.*, 2013; Becker *et al.*, 2015). The National Research Council's report on discipline based education research has called for evaluation of the POGIL approach and research in upper-level courses, such as physical chemistry (NRC, 2012a, 2012b).

The POGIL approach applies social constructivist theories of learning to develop curricular materials and facilitation strategies that prompt students to co-construct and apply knowledge. A POGIL classroom involves a significant portion of collaborative small group work intended to promote higher order thinking and application of knowledge (Moog and Spencer, 2008). Students are guided through a process of exploration, concept development, and application. In the thermodynamics workbook used in both of the classrooms under study, each activity poses a focus question for which students do not typically have the chemical knowledge to answer. Students then work through a series of critical thinking questions (CTQs) that build on previous units and help them construct models specific to the activity. Final CTQs typically ask students to describe and explain the concepts they have been constructing throughout the activity (Moog and Spencer, 2008). Each activity concludes with exercises that provide further opportunity to apply concepts constructed in the activity. Though POGIL provides curricular materials and a general approach, it leaves room for the instructor to make decisions about the actual implementation and facilitation based on their classroom's needs.

Methods

Theoretical orientation

This work was shaped by the sociocultural perspective (John-Steiner and Mahn, 1996). The primary tenet of the sociocultural perspective is that knowledge is co-constructed by individuals in a social and cultural context through the medium of language (Geelan, 1997). The social construction and individual construction of knowledge occur simultaneously and are interdependent (John-Steiner and Mahn, 1996). Vygotsky theorizes that intermental (social) activity in fact promotes intramental (individual) learning (Mercer *et al.*, 2004). This occurs through a process of internalization by the individual. The learning process is housed in discourse. Therefore, the success or failure of an educational intervention may be attributed to the quality of the discourse rather than simply the students' or teacher's capabilities (Mercer, 2004). Argumentation is one form of discourse we have chosen to evaluate, as it is a core scientific practice.

The sociocultural perspective theoretically supports this work in its justification of the use of POGIL for facilitating small group and whole class discourse as a means of supporting individual understanding. It further supports the method of analysis used in this study. As learning is mediated by language, analyzing the classroom discourse is the most appropriate method for identifying instances of learning or discursive moves that hindered learning.

Analytic framework: toulmin argument pattern

The widely used Toulmin Argument Pattern (TAP) presented in Fig. 1 was used to identify, model, and organize arguments (Erduran, *et al.*, 2004; Jimenez-Aleixandre and Erduran, 2008). The core of the argument includes a conclusion, some data or evidence supporting the claim, and an explanation connecting the data to the claim. In certain instances, backings are required to justify or support a warrant. Qualifiers provide the limitations or restrictions to the core of the argument. In the context of physical chemistry, qualifiers often appear as a description of limitations for a formula or model. Rebuttals identify a shortcoming in an argument by undermining either the use of a component in the core argument or the content of a component in the core argument.

To identify arguments using TAP, transcripts from the whole class videos were analyzed for claims, which often took the form of the answer to a POGIL prompt. The presence of evidence or data to support the claim qualified the unit of text as an argument.

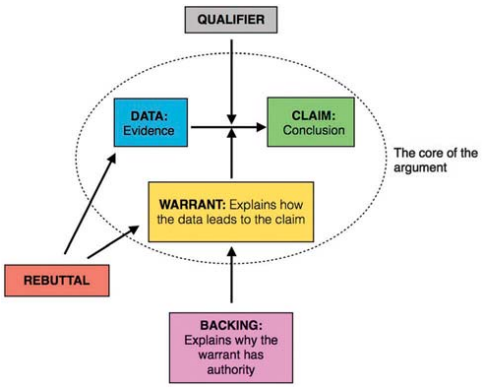

Fig. 1 Toulmin Argument Pattern (Adapted from Erduran *et al.*, 2004).

Perhaps the most challenging step in using TAP was distinguishing between claims, data, warrants, and backings (Erduran, 2007; Kaya, 2013). Indicator words such as "so" or "because" were useful for identifying what was being concluded (claim) or why the conclusion was drawn (warrant). For arguments concerning phenomena or empirical data, warrants frequently served an explanatory function. For arguments concerning mathematical derivations or problems, warrants tend to be more algorithmic, describing steps taken to move from the data to the claim (Rasmussen and Stephan, 2008). Both of these types of arguments are present in physical chemistry discourse.

Participants and data collection

Institutional review board approval was obtained to protect human subjects prior to data collection and analysis in this study. Two classrooms using the POGIL Physical Chemistry curriculum were explored in this study. Table 1 describes the settings and participants of the two classrooms.

Some of the key differences between the two implementations were the instructors' experiences with implementing POGIL, the physical chemistry topics covered, and the presence of whole class discussion. Both instructors became involved with the larger POGIL project since first using it in their classroom, with Dr Black focusing on instructor facilitation and Dr Green focusing on developing POGIL materials. While Dr Black iteration covered exclusively thermodynamics, Dr Green iteration covered all traditional physical chemistry topics. While the order and timing of the use of activities differed, for the purpose of this study we analyzed classroom discourse while students completed the same set of chemistry topics. In the 2010 implementation, class time was split between small group discussion and whole class discussions with very little lecture. In the 2013 implementation, time was split primarily between small group work and lecture. Though there were instances of students asking questions during the lectures during the 2013 implementation, they were not frequent. Video data of entire class periods were collected with cameras aimed at collecting small group interactions and whole classroom interactions (Cole *et al.*, 2012).

Data analysis

The videos of each class period were transcribed verbatim. The classroom transcripts were then analyzed using Toulmin's Argument Pattern (TAP). To extract arguments, researchers carefully read through transcripts to identify the presence of claims. Usually, these were responses to prompts in the POGIL activities. If a claim was joined by any evidence, it was extracted as an argument. There were instances when the data was implied based on context, rather than being explicitly verbalized. Discourse surrounding the claim and data were analyzed for fit to a component of Toulmin's model (*e.g.* warrant, backing, qualifier). Two separate graduate student chemistry education researchers independently generated argument logs, lists of arguments organized according to the TAP, for each transcript. After this, the entire research team, made up of the two graduate students and their faculty advisors, met and discussed discrepancies until complete consensus was reached. The product of this step was an argument log for each class period that included every argument along with its corresponding POGIL question. When extracting arguments, discourse was often paraphrased to fit into the TAP model. This served to condense large amounts of text into a concise form. When paraphrasing contributed to a loss of meaning, the original text was used in the argument log. Italics were used to indicate original quotes from students. These argument logs were used for all further analysis. Below is an excerpt to illustrate the layout and function of an argument log.

10.13.10 Argument log
Whole class discussion
[00:01–02:42] ChemActivity T9, CTQ 4a
Claim: $dA = dU - TdS$ (Elliot)
Data: $A = U - TS$ (given in book)
Warrant: Apply state function to data (Elliot)
Rebuttal: Why did T come out? Did you chain rule? (Quentin)
Resolved claim: $dA = dU - TdS - SdT$ (Jerome, Elliot, Caprice)
Data: $dA = dU - d(TS)$ (Caprice)
Warrant: Use the chain rule (Jerome)

The second stage in analysis involved coding these arguments with the modes of reasoning in the Chemical Thinking Learning Progression (CTLP). This level of analysis allowed us to characterize the modes of reasoning used within each argument as a whole adding further dimensions of analysis. Ultimately it was used to reveal the types of reasoning students use within arguments. Additionally, the modes of reasoning in the CTLP allow for the consideration of the entire argument as a unit, rather than consideration of its individual components. Arguments were

Table 1 Classroom and participant demographics

	2010	2013
	Instructor: Dr Black	Instructor: Dr Green
Instructor experience	10 years of implementing POGIL	7 years of implementing POGIL
Setting	Public University, ~14 000 students Thermodynamics Spencer, Moog, & Farrell POGIL materials	Private college, ~1000 students Physical Chemistry I & II Spencer, Moog, and Farrell POGIL materials
Number of participants	18 students 5 Females 13 Males	10 students 3 Females 7 Males
Participant demographics	Third & fourth years At least 1 semester of calculus	Second through fourth years 2 semester of Calculus (except 1)
Class time	1/3 to 1/2 class small group work, rest whole class discussion	1/2 to 2/3 time small group work and 1/3 to 1/2 lecture

Table 2 Features of modes of reasoning in CTLP used to analyze arguments

Mode	Features
Descriptive	• Salient properties are recognized • Explicit properties are verbalized • Phenomenon is instantiation of reality • Reasoning based on experiences from daily life
Relational	• Explicit and implicit properties are highlighted • Spatial and temporal relations are noticed • Phenomenon is effect of single variable (no mechanism)
Linear	• Mechanisms proposed that involve linear cause-effect relationships
Multi-component	• Mechanism weighs effects of several variables

labeled as descriptive, relational, linear causal, or multicomponent based on the features described in Table 2.

In order to categorize arguments, the first author read arguments along with the corresponding POGIL prompt. If the argument only provided information present in the prompt in order to respond to the prompt, it was assigned a descriptive code. Arguments that consisted of statements that described the phenomenon or question, it also received a descriptive code. Relational codes were assigned to arguments that highlighted a single relationship between variables to justify a claim or if the claim was made assuming a relationship between variables (*e.g.* "work was done because the piston went up"). Linear arguments included steps linking variables together in a linear cause and effect sequence used to achieve some outcome. The multicomponent code was assigned to arguments that explicitly considered more than one variable as simultaneously contributing to an outcome.

The first author presented a description of these codes to two chemistry education graduate students and they each coded an argument log for one class period. The codes for each argument were discussed until the three coders reached a complete consensus. This discussion prompted the first author to refine the code descriptions and code all of the arguments again. This round of coding resulted in only assigning a few arguments new codes.

It is important to note that the modes of reasoning used in this work are only one aspect of this learning progression. We considered the disciplinary crosscutting concepts in so far as we identified chemical mechanism, chemical identity, and structure–property relationships as the most widely used in both of the classrooms studied (Sevian and Talanquer, 2014).

Results

Examples were found for each type of student reasoning: descriptive, relational, linear, and multicomponent. Fig. 2 shows that the classrooms differed in their chemical thinking distribution; however, the overall reasoning patterns are similar. It is important to note that because argumentation is a process skill, valid arguments consisting of claims grounded in evidence

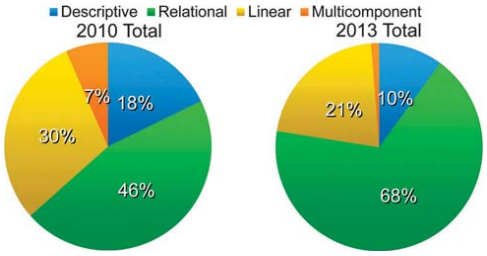

Fig. 2 Overall distribution of reasoning in both classrooms.

can be made by students irrespective of the complexity of reasoning. Because of this, arguments using all levels of reasoning reflect positively on students' skills in constructing arguments.

Descriptive

Descriptive arguments did not contribute new information. Rather, they were repetitive, focusing solely on superficial features of the prompt. Table 3 shows an example of a POGIL prompt eliciting descriptive reasoning. In this argument, the student is interpreting the reaction as listed in the problem. The student correctly identifies that one mole of $A_{(g)}$ and one mole of $B_{(g)}$ means that there are two moles of reactants. However, this argument indicates only consideration of explicit features of the problem, that is, the chemical reaction. This argument is not surprising, considering the prompt specifically asked the students to elaborate on what information the symbolic representation of the chemical reaction provides.

Table 4 shows the students in 2010 and 2013 making different claims, but using the same data and reasoning. It is clear that they are describing reactants in order to respond to the prompt. The claims they are generating rely on identifying reactants as molecules or elements as they are written. Similar to the previous example, the question is prompting the students to describe features of the problem to make a claim. The prompt provides seemingly explicit conditions for identifying an enthalpy of formation reaction and yet the students from 2010 and 2013 do not generate the same claim. The practice of generating arguments revealed areas of possible confusion on the part of the students. Though it seems like they are not using complex reasoning or generating new information, the arguments they constructed to make descriptive claims reveal their reasoning and interpretation of the problem.

Table 3 Descriptive argument generated in 2010 in response to prompt to consider model reaction

POGIL prompt	2013
The chemical reaction of A and B goes to completion: $A_{(g)} + B_{(g)} \rightarrow C_{(g)} + 2D_{(g)}$ $\Delta_r H = 0$ Before the chemical reaction occurs, what is the total number of moles in the container?	Claim: There are two moles of gas before the chemical reaction occurs (Elliot) Data: Model 2 information (book) Warrant: 1 mole of gas A and 1 mole of gas B (Rosalind)

Table 4 Descriptive arguments generated in both classrooms in response to prompt to identify enthalpy of formation reactions

POGIL prompt	2010	2013
$Mg_{(s)} + CO_{(g)} + O_{2(g)} \rightarrow MgCO_{3(s)}$ $MgO_{(s)} + CO_{2(g)} \rightarrow MgCO_{3(s)}$ $Mg_{(s)} + C_{(s)} + 3/2\ O_{2(g)} \rightarrow MgCO_{3(s)}$ $BaCO_{3(s)} \rightarrow BaO_{(s)} + CO_{2(g)}$ $CO_{(g)} + 1/2O_{2(g)} \rightarrow CO_{2(g)}$ $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ In which of the above reactions is the product the result of the reaction of the elements that compose it, each of the elements being in their stable states at 1 bar?	Claim: C and F are a result of the reaction of the elements that compose it (Jerome/Jamal/Book) Data: Reactions from the book (book) Warrant: All the other reactions have molecules (Jerome/Jamal)	Claim: In reaction F, the product is the result of the reaction of the elements that compose it (Mark) Data: Model 4 chemical reactions (Mark)

Relational

The students in both 2010 and 2013 primarily used relational reasoning. Arguments using relational reasoning relied on a relationship without providing any sort of causal justification. Table 5 provides examples of this type of argument. Excluding Dr Green's backing in 2013, student arguments took the form ''If this variable is dependent upon another variable that is a state function, then it is a state function.'' Rather than considering the nature of enthalpy or internal energy in order to make claims about whether or not the variables were state functions, students exclusively considered the relationship between all the variables. Dr Green's backing inputs reasoning based on how pressure and volume change in a system in order to decide if they should be state functions. The backing provided by Dr Green illustrates a more complex causal model in which more thorough justifications indicating an understanding of pressure and volume are used to support the claim that pressure and volume are state functions.

In another example, Table 6 shows students' use of the relationship between the total entropy change and spontaneity of a system. In both iterations, students claimed that the total change in entropy would be positive for the process because the process is spontaneous. Dr Black aims to move students past only considering spontaneity and entropy change as mathematical values to considering them as variables that describe a process. Earlier arguments from this activity reveal that this justification is grounded in the definition for a spontaneous process provided in the POGIL information. Table 7 includes Jamal's argument when prompted to consider a process in which the final total entropy was larger than the initial total entropy.

Caprice uses the same reasoning for the reverse process, shown in Table 8. All of these arguments draw on the relationship between spontaneity and total entropy change to justify claims. None of the arguments indicate an understanding of spontaneity, entropy, or the phenomenon (hot brick in cold water). There were no instances of students making sense of this relationship. This is partially due to the description of this concept in the POGIL curriculum in which a spontaneous event is defined as having a positive total entropy change. However, this indicates that Caprice and Nathan are simply quoting the POGIL text with no evidence of interpretation or sense making. More complex causal arguments would ideally incorporate reasoning

Table 5 Relational arguments generated in response to prompt to determine if pressure, volume, and enthalpy are state functions

POGIL prompt	2010	2013
Recall that energy, U, is a state function (or that dU is an exact differential). Is PV a state function? Is H a state function?	Claim: H is a state function (Class) Data: $H = U + PV$ (book) Warrant: It is a sum of state functions P, V, and U (Jake)	Claim: PV a state function (Garrett/Mark) Data: U is a state function (Mark) Warrant: *Because it's a measure of energy, which is a state function* (Garrett) Backing: *The pressure is what it is, it doesn't matter what path the system took to get there. And the same with the volume* (Dr Green)

Table 6 Relational arguments generated in response to prompt to predict spontaneity of a process

POGIL prompt	2010	2013
Imagine tossing a hot brick into cold water in an adiabatic enclosure. Assume that the resulting process does not affect the volume of the brick or the water. Can you determine the sign and/or magnitude of ΔS_{tot} for this process? If so, provide this information. If not, explain why not.	Claim: ΔS total is positive. (Callum) Data: Because it's spontaneous (Callum) Warrant: *Yeah, the change has to be spontaneous*, ΔS *system has to be spontaneous, so then the total has to be spontaneous*. (Tice) Clarifier: So the total can't be spontaneous, the process can be spontaneous, but the math can't be spontaneous.(Dr Black)	Claim: ΔS total for the process has a positive sign (Garrett) Data: Because it is spontaneous (Garrett)

Table 7 Relational argument in response to prompt to predict spontaneity of a process

2010
Claim: Yes, the process is spontaneous (Jamal) Data: (S_{tot}) final > (S_{tot}) initial (Book) Warrant: *That was part of the definition of spontaneous* (Jamal)

Table 8 Relational argument in response to prompt to predict spontaneity of a process

2010
Claim: No the process is not spontaneous (Caprice) Data: (S_{tot}) final < (S_{tot}) initial (Book) Warrant: Because of the definition of spontaneous (Caprice)

about entropy and spontaneity, as well as the phenomenon at hand, to justify and predict an outcome. What these two arguments above suggest is that the relationship between spontaneity and total entropy change was assumed to be sufficient justification for claims without a supporting explanation or interpretation.

Relational reasoning is particularly useful for revealing how students use relationships to justify claims. However, relational arguments often lack evidence of students' understanding of a certain relationship. More complex argumentation, including more robust warrants and more frequent rebuttals, can serve to prompt students to make explicit their understanding of scientific relationships.

Linear

Students in both groups demonstrated linear reasoning, which included some linear cause and effect mechanism. These arguments tended to take one of two forms, mathematical or conceptual. The structure of mathematical arguments usually included a linear, stepwise description of the mathematical operations students completed to move from the data, or initial equations, to claim, or final output.

The arguments in Table 9 show the sequential reasoning employed by the students to arrive at some mathematical product. In both cases, students list mathematical steps taken to complete the derivation. This is most frequently how students discussed any mathematical reasoning. This is noteworthy because one of the only times we see students use linear, stepwise reasoning with ease is when they are describing their mathematics. The burden to use linear reasoning is not a priority when explaining phenomena. In that case, relational reasoning without explanation is often considered sufficient.

There were instances of linear causal arguments for phenomena and concepts, but they did not follow as consistent of a structure as that observed in the mathematical arguments. In response to the prompt in Table 10 that required them to compare the final temperatures for neon and nitrogen upon the addition of the same amount of heat, Qi generated a linear argument to justify his claim.

Qi argues neon would have higher temperature exclusively from the perspective of nitrogen, explaining that because nitrogen has bonds that would absorb energy, it will have a lower temperature. It is important to note that there are features that are implicitly included in this argument. The reason that we can conclude that they are present is because they provide the connection between features that were made explicit (in contrast to relational reasoning where sequential reasoning was not employed and mechanistic steps were not made explicit). In order for Qi to draw the conclusion that he did, she had to assume that having more energy contributes to higher temperature. Providing a mechanism in an argument is revealing of steps the students thought important to verbalize and the steps that they assume are implicit.

Some linear arguments were a hybrid between mathematical and conceptual arguments. This hybrid type was particularly prevalent in arguments concerning Hess' law. Students in both groups used reasoning about the chemical process to inform how they completed the mathematical operation. These arguments still assume a linear description of steps taken to reach a

Table 9 Linear arguments generated in response to prompt to complete a derivation

POGIL prompt	2010	2013
Show how $\Delta S_{surr} = \frac{\Delta H_{surr}}{T}$ can be obtained from $dS = \frac{dq_{rev}}{T}$	Claim: ΔS_{surr} is equal to delta H over T (Jamal) Data: $dS = dq_{rev}/T$. T is constant, (Jamal) Warrant: *And you pull that out and integrate so and integral of ds = 1 over T integral and dq. That gives you ΔS is equal to 1 over dq. And if dh is equal to q at constant pressure and temperature, then ΔS is equal to 1 over TΔH*. (Jamal)	Claim: $\Delta S = \Delta H_{surr}/T$ (Garrett) Data: $dS = dq_{rev}/T$, $dH_{surr} = dq_{surr}$ (Garrett/book) Warrant: *So you have dS equals dq surroundings over temperature, and the equation you earlier, and since we just said in (9)a that dH surroundings equals dq surroundings, we can substitute that in. And then take a derivative I mean the integral* (Stephanie)

Table 10 Linear argument generated in response to prediction prompt

POGIL prompt	2013
Consider 1 mole samples of Ne and N2 at the same temperature T. Equal amounts of heat are added to each sample under otherwise identical conditions. Predict whether the final temperatures of the two samples will be the same or different. If different, predict which will have the higher final temperature. Explain clearly	Claim: Neon would have a higher temperature than N_2 upon input of the same amount of energy (Qi) Data: *It has like bonds* (Qi) Warrant: So the bonds would absorb some energy (Qi)

Table 11 Linear arguments generated in response to prompt to consider the vaporization of water

POGIL prompt	2010	2013
Use these data [enthalpies of formation for gaseous and liquid water] and Hess' law to calculate $\Delta_r H$ for the following reaction $H_2O_{(l)} \rightarrow H_2O_{(g)}$	Claim: ΔH for $H_2O_{(l)} \rightarrow H_2O_{(g)}$ = difference between two heats of formation (44.01 kJ mol^{-1}) (Jerome/Quentin)	Claim: The ΔH of reaction is 44.01 kJ mol^{-1} (implied)
	Data: $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(l)}$ $\Delta_r H_o = -285.83$ kJ mol^{-1} $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(g)} \Delta_r H_o = -241.82$ kJ mol^{-1} (Text)	Data: heat of formation reactions and ΔH values (book)
	Warrant: The top equation needs to be flipped because you start with liquid water, flip it so the net equation would end with gas (Jerome/Liam) Backing: A positive value makes sense since you are vaporizing the water. (Liam/Quentin)	Warrant: you add the reverse reaction, because you are going from H_2 liquid to H_2 gas, so you want to add the reverse (Stephanie)

mathematical output, but they include justifications grounded in the chemical process. Table 11 shows similar arguments generated in both classrooms to calculate the enthalpy change for vaporization of water.

In the arguments presented in Table 11, students determine an enthalpy of reaction for the vaporization of water equaling 44.01 kJ mol^{-1}. Using Hess' law, they warrant switching the sign of the enthalpy of formation of liquid water and adding the enthalpy values to determine the total enthalpy change for the reaction. Particularly noteworthy in this argument is Liam and Quentin's explicit evaluation of the output value in which they rationalize the positive value based on the phenomenon. Students draw from the phenomenon to provide conceptual justifications for the mathematical steps taken to calculate an output value.

In another example of a hybrid structure argument, Dr Black builds on Sam's claim with a conceptual explanation, shown in Table 12. Dr Black explained the mathematical substitution ($-P\mathrm{d}V$ for $\mathrm{d}w$ in the first law equation) with a more conceptual description of the energy change sourcing from the work change. Dr Black was intentional about modeling how mathematical, linear reasoning is meaningful for understanding thermodynamic concepts. Linear arguments are distinct in their inclusion of cause and effect reasoning. In the arguments presented above, the students propose a mechanism in which one step (mathematical or phenomenal) leads to another and eventually an outcome.

Multicomponent

Multicomponent arguments were the least frequent indicating the difficulty of considering multiple variables as contributing to an outcome. During the discussion of neon and nitrogen, two different groups from the 2010 implementation generated multicomponent arguments shown in Table 13.

In response to this problem, we see two different responses using multicomponent thinking. Reed concludes that neon would be hotter as it is lighter so it will move faster while nitrogen has bonds that heat will be used to break, so there is less energy to go into increasing temperature. The warrant that the heat added would break nitrogen bonds indicates an incorrect understanding of bond energies. However, he was correct in considering nitrogen's bonds and the difference in mass between nitrogen and neon as significant. Quentin's argument builds on Reed's by explicitly considering both neon and nitrogen, specific vibrational modes, rotational, and translational modes. Both of these arguments indicate that students recognize that multiple

Table 12 Linear argument generated in response to prompt to provide an equation

POGIL prompt	2010
Use your answer to CTQ 8 and parts a and b above to provide an equation relating $\mathrm{d}U_{sys}$ to pressure and volume for an adiabatic, reversible process.	Claim: $\mathrm{d}U_{sys} = -P\mathrm{d}V$ (Sam) Data: In an adiabatic system, $\mathrm{d}U = \mathrm{d}q + \mathrm{d}w$, $\mathrm{d}q = 0$, $\mathrm{d}w = -P\mathrm{d}V$ (CTQ8, 10a, 10b) Warrant: *So for an adiabatic system where dq = 0, then the change in energy comes from changes due to work* (Dr Black)

Table 13 Multicomponent arguments generated in response to prompt to predict temperature change for a process

POGIL prompt	2010	2010
Consider 1 mole samples of Ne and N2 at the same temperature *T*. Equal amounts of heat are added to each sample under otherwise identical conditions.	Claim: Ne is hotter (Reed's board)	Claim: Neon would be hotter than N2 (Quentin)
	Data: Because neon is lighter. (Reed)	Data: Neon doesn't have any bonds (Quentin)
Predict whether the final temperatures of the two samples will be the same or different. If different, predict which will have the higher final temperature. Explain clearly	Warrant: *it'll move faster with the same amount of heat added. And because there's triple bond between nitrogen. The amount of heat given in the system, part of it will be considered to break the bonds*. (Reed/Elliot)	Warrant: Nitrogen has bonds, bonds can devote energy to stretching, straining, and you've also got rotational and those other types of motion. Whereas the Neon just has translational (Quentin)

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Table 14 Multicomponent argument generated in response to prompt to predict entropy change for a process

POGIL prompt	2010
As the temperature associated with the system is raised above 0 K, do you expect that the entropy of the system will increase or decrease? Explain your reasoning.	Claim: As temperature increases, entropy increases because of molecular movement (Jerome/Summer) Data: Definition of a solid is no molecular movement Warrant: Because the lower you go [temperature], the less movement there is (Summer) Backing: Because you have more distributed energy states (Thaddeus)

variables (*i.e.* mass difference, bond difference, *etc.*) give rise to neon ultimately having the higher temperature. The warrants in multicomponent arguments tend to be the most complete and thorough, making consideration of multiple variables explicit. In the argument shown in Table 14, the students are considering entropy by discussing multiple facets of the concept.

This argument provides evidence of students making sense of the concept of entropy by considering the definition of a solid, molecular motion, temperature, and energy states. Multicomponent arguments are especially complex, but are most apt for making sense of complex concepts such as entropy, which is inherently multifaceted. Because of this complexity, multicomponent arguments were by far the least frequent. These constitute quite sophisticated arguments, including thorough and complete justifications, in which students make their reasoning clear.

Conclusions

We used modes of reasoning in the CTLP to analyze and classify arguments generated by students in POGIL physical chemistry classrooms. Results showed that physical chemistry students did not frequently use descriptive reasoning, the least complex mode of reasoning. Students primarily used relational reasoning across both classrooms. Relational arguments draw on a relationship without explaining the relationship as sufficient justification for an outcome. These arguments were frequently generated in response to conceptual problems, indicating a possible comfort with drawing only from relationships to make sense of phenomena. Students did propose mechanisms in the form of linear and multicomponent arguments. Linear arguments generally took one of three forms, mathematical, conceptual, or hybrid. In the context of physical chemistry, students were frequently required to perform a derivation or calculate a value. These tasks elicited mathematical linear causal arguments that often follow a pattern of claim (output equation or value), data (starting equation), and warrant (how starting equation leads to final output). This pattern of argument serves to answer the question of ''how'' a mathematical output was computed. Employing causal reasoning to construct arguments in response to conceptual problems occurred less frequently, evidenced by the lower percentage of linear and multicomponent arguments.

The results from our study demonstrate that students can construct arguments without necessarily including a causal mechanism. This counters what was expected based on previous work highlighting the usefulness of argumentation for prompting students to articulate their reasoning (Berland and Reiser, 2009). In this work, linear and multicomponent arguments that included evidence of cause and effect reasoning were more complete and thorough than the relational and descriptive arguments. That is, linear and multicomponent arguments were indicative of students verbalizing more of their reasoning and understanding; whereas relational arguments included little evidence of the students' understanding of relevant concepts. This points to an important relationship between how thorough an argument is and the type of reasoning used. Generating an argument that is clear, coherent, and comprehensive often requires students to employ cause and effect reasoning to sufficiently justify a claim.

Our analysis suggests that a link exists between the nature of the question or problem and the mode of reasoning that students use. There was a clear link between problems requiring the student to derive an equation or provide an expression and linear causal arguments that took a mathematical form that resulted. However, other links were less strong. For example, some multicomponent arguments were generated in response to questions prompting students to make some sort of prediction. Relational arguments, on the other hand, resulted from every question type. Although there appears to be a link between the question and the resulting argument, more research is needed to fully understand these relationships. One complicating factor is the role of instructor facilitation and the learning environment. Although examples of each type of reasoning was found in both cases, the degree to which they were used differed. Even though the students used the same instructional materials in both cases, the order of activities, use of whole class discussion, and other aspects of implementation varied. A more thorough investigation of these differences in facilitation has been conducted and will be detailed in a forthcoming publication.

Using the modes of reasoning in the learning progression on chemical thinking (CTLP) equipped us to distinguish arguments based on complexity of reasoning. This is the first instance of the CTLP being used to analyze classroom discourse. The CTLP was especially useful for characterizing arguments aimed at explaining an outcome of a phenomenon. It was not as insightful for characterizing arguments that included mathematical derivations or calculations, though these types of arguments are especially frequent in the context of physical chemistry.

Implications for teaching and research

One desired outcome of advanced chemistry coursework is the ability to generate robust arguments that use sophisticated causal models. To support students in developing this skill, instructors can use student argumentation as a platform for identifying and evaluating students' causal reasoning skills. Providing students with an argument model and making time in the classroom for students to build arguments offers the instructor exposure to students' reasoning. Throughout the course, explicitly prompting students to construct arguments can establish argumentation as a normative form of discourse in the classroom. Having students create arguments is not enough, however, instructors must also be attentive to the reasoning students are employing in their arguments.

We recognize that different levels of reasoning are likely to be appropriate for considering different problems. In the context of physical chemistry, as students are constructing an understanding of thermodynamic concepts and relationships, they might rely primarily on relational reasoning. In some cases, this may be sufficient for sense-making. However, reliance on this reasoning may limit students' growth as they move forward in thermodynamics. For concepts that are abstracted from observable variables, such as entropy or Gibbs energy, a coherent understanding requires synthesizing an understanding of mathematical derivations with an understanding of chemical and physical implications. In order to make sense of chemical phenomena or solve complex problems, one must be able to consider multiple variables and how they interact with each other.

We propose two approaches instructors may use as they help students develop reasoning skills for understanding complex phenomena. Instructors can support students in developing this ability by modeling more complex causal reasoning in their lectures. Perkins and Grotzer (2005) found that explicitly teaching complex causal models improved students' causal reasoning. Using the modes of reasoning applied in this work, instructors are encouraged to explicitly discuss linear causal and multicomponent models, provide examples of each, and model these modes of reasoning in the arguments and explanations in their lectures. By explicitly modeling this reasoning, students are better equipped to apply it in their own reasoning. Instructors can also collaboratively construct arguments with their students to contribute variables students may not have included. This contribution can come in the form of core argument components (*i.e.* providing data or a warrant) or other components (*i.e.* rebutting or qualifying a student's argument). The benefits of collaboratively constructing arguments with students is two-fold. It supports students' causal reasoning by including variables students may not have considered. It also supports students' argumentation by building more comprehensive arguments.

In this work, we have demonstrated the utility of the modes of reasoning in the CTLP as an analytical tool and we have used it to describe the types of reasoning used in two POGIL physical chemistry classrooms. More research is needed to understand when students employ certain types of reasoning and how to scaffold these reasoning skills with students. This will involve elucidating the relationship between the types of reasoning students use and the problems being solved. An understanding of this relationship can be used to design and evaluate interventions for improving students' causal reasoning and argumentation.

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